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GEOLOGICAL MAGAZINE

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EDITORIAL NOTE

AT the beginning of 1940, when the present Publishers generously assumed responsibility for the *Geological Magazine*, they adopted a new paper and a new and more readable type, and issued the Magazine in two-monthly instead of monthly parts. The new format had to be changed abruptly in the middle of 1942, when drastic paper restrictions were introduced which compelled reduction in the number of pages ; and at the beginning of 1943 the subscription price was reduced to 30*s*. a year as the Editors and Publishers did not wish to profit by this compulsory reduction in size. We are now, for the first time, in a position to return to the 1940 format and to increase again the number of pages, but in the interval the cost of printing has increased by nearly 30 per cent. It would not be possible to resume the full size of the 1940 volume without considerably increasing the cost of the Magazine to meet these increased charges, and we are proposing, provisionally at least, to increase the size of each part to 64 pages, whilst maintaining the reduced price of 30*s*. a year. Any further increase in size will have to be met either by increased circulation or increased price, and it is needless to add that we should much prefer the former alternative.

R. H. R.
O. M. B. B.

A Deep Boring at North Creake, Norfolk

By P. E. Kent (D'Arcy Exploration Company)

As a result of regional studies based on the stratigraphical successions of both the English Midlands and the Low Countries, it was concluded in 1940 that there was a generous development of Mesozoic rocks in Northern Norfolk, and a probability of the presence of Carboniferous rocks (Lees, 1946). It was considered that an examination of the oil-producing potentialities of Eastern England would be incomplete without exploration of this area, and in 1945, after a preliminary seismic survey, the D'Arcy Exploration Company put down a boring to test the pre-Mesozoic rocks at North Creake, eleven miles east-south-east of Hunstanton.

The forecast for the Mesozoic rocks proved to be accurate in considerable detail, but it was unfortunately found that the Palaeozoic rocks were absent, and that at North Creake the Trias rests directly on the Pre-Cambrian basement. This indicates that North Norfolk overlies a broad pre-Mesozoic " Schwelle ", which extends northwards beyond the line joining the featheredge of the Carboniferous in the Midlands and in Belgium.

In the following account, which is published by kind permission of the Chairman and Directors of the Anglo-Iranian Oil Company, Ltd., the tabulated principal data are followed by a detailed account of the succession with a discussion of the correlation. All measurements are in feet.

Thanks are due to Dr. James Phemister and Mr. R. V. Melville, of the Geological Survey, and to Miss P. S. Walder, of Reading University, for their valuable assistance during investigation of the succession.

Bore-Hole Data

Position of bore-hole. 0° 45′ 41·75″ E., 52° 54′ 45·75″ N. Approximately ½ mile N.N.E. of North Creake Church. Elevation of rotary table (datum for measurements) 71 O.D. Drilling 13th May, 1945, to 15th June, 1945.

	Thickness.	*Depth of Base.*
Chalk	471	471
Upper Greensand	10	481
Red Chalk	6	487
Lower Greensand	216	703
Kimeridge Clay	160	863
Ampthill Clay	85	948
Oxford Clay and Kellaways Beds	184	1,132
Cornbrash	6	1,138
Great Oolite Series	97	1,235
Lias and Rhaetic	555	1,790
Keuper	513	2,303
Bunter	132	2,435
Pre-Cambrian penetrated to	197	2,632

Details of Succession

No cores were taken until the Pre-Cambrian was reached, and the succession has been determined by examination of cuttings brought to the surface by the mud flush. These have yielded fragmentary fossils which are of considerable assistance in classifying the Jurassic beds. Depths of formation changes have been corrected for sample lag with the assistance of data from a " rate of penetration " recorder.

1. *Upper Cretaceous—White and Red Chalk, 487 feet.*

Samples through the White Chalk were of doubtful quality, as caving caused contamination, especially in the lower part. In the following summary material considered to be out of place is enclosed in brackets.

	Thickness.	*Depth to Base.*
White Chalk 471 feet.		
Soft chalk, giving very small cuttings, and white and grey flint	119	119
Harder chalk with dark grey and brown flint	45	164
White chalk with large quantities of black flint	30	194
White chalk with moderate quantities of brownish and black flint	143	337
Soft white chalk, and a little yellowish chalk in the lower part [with brown and grey flint and dark grey silty shale]	30	367
White chalk with traces of a yellowish band 60 feet down [and subordinate grey, brown, and dark flint]	84	451
Greyish and yellowish chalk, grading up to white	20	471
Upper Greensand 10 feet.		
Slightly calcareous light grey very fine sandstone or siltstone with foraminifera (preserved in glauconite ?) and occasional limonite grains	10	481
Red Chalk (*Hunstanton Red Rock*) 6 feet.		
Pale yellow chalk and orange chalk with scattered grit grains, and deep red very gritty chalk with *Inoceramus* fragments. A few " lydite " pebbles	6	487

As a result of the degree of contamination of the samples it has not been possible to sub-divide the White Chalk on lithological evidence. It is hoped, however, that Mr. E. W. Mitchell will be able to accomplish this by foraminiferal studies.

Whitaker and Jukes-Browne (1899) regarded the surface Chalk of this valley as low in the Coranguinum zone, and at a seismic shot point 650 feet N.E. of the bore-hole site Mr. Mitchell reported that foraminiferal assemblages suggested that the Coranguinum/Cortestudinarium boundary lay at 40 feet below surface. If this applies also to the bore-hole site, it suggests that the lower zones of the Chalk are thicker than is usual in North Norfolk, although not thicker than in the Cambridge district. Unfortunately fossils collected from the

surface excavations at the bore-hole site do not assist much; Mr. R. V. Melville identified *Echinocorys scutata* Leske and *Thecidium wetherelli* Morris but was only able to comment that they indicate a horizon not lower than Coranguinum.

The fine sandstone at the base of the Chalk is to be regarded as Upper Greensand, using this as a facies term without prejudice as to age. It could be a representative of the Cambridge Greensand, which (according to Spath) is slightly later than the ammonite-bearing part of the Red Chalk. We are not aware of another case of the two beds occurring together at a single locality.

The Red Chalk development appears to be quite normal, and it shows the usual generous admixture of sandy material of Carstone type.

The incoming of the Upper Greensand only eleven miles from the type section at Hunstanton affords a measure of support for Rastall's postulated non-sequence between the White and Red Chalk (1930), although it is at present not clear how it is to be reconciled with the palaeontological data cited by Kitchin and Pringle (1932).

The Upper Greensand heavy minerals were examined by Miss P. S. Walder for comparison with the Carstone and Red Chalk assemblages listed by Rastall (1930). Unfortunately the bulk of material available was necessarily very small, but about 500 grams were boiled with acid. The solute gave positive reactions for the ferrous and ferric ions, and showed only a trace of phosphate—the last in contrast equally to the beds beneath and to the Cambridge Greensand of the area to the south. The total number of grains obtained from the rock was small, and the list of species might be considerably extended if more material became available. There are, however, certain definite differences from the lists for the beds below; tourmaline, magnetite and leucoxene are notably more abundant than kyanite and staurolite (particularly abundant in the Carstone) while blue hornblende and colourless pyroxene (characterizing the clay parting above the Red Rock) have not been found. The following list shows the minerals in order of abundance :—

Quartz—subrounded, full of inclusions	abundant
Magnetite	abundant
Pyrite	abundant
Leucoxene	abundant
Tourmaline (brown, or particoloured brown and blue)	8 grains
Kyanite (some grains showing undulose extinction)	7 "
Zircon (yellow and colourless)	4 "
Chlorite	3 "
Garnet	3 "
Staurolite	2 "
Rutile	1 "
Plagioclase	1 "
Microcline	1 "
Topaz ? (very small)	?

This evidence provides support for Rastall's postulate of a non-sequence between the Red Rock and the Lower Chalk, for it indicates a time interval sufficient for two changes in the provenance of sediment—one from the Red Chalk to the Upper Greensand, the second from this to the Lower Chalk.

2. *Lower Cretaceous.* 216 feet

Upper Carstone 28 feet.		
Yellow marly sandstone	1	488
Greenish brown friable ferruginous sandstone, and dark blue grey cemented ferruginous sandstone (glauconitic and sometimes limonitic) increasing downwards. Clear, yellow, and pink quartz pebbles and lydites . . .	12	500
Poorly cemented dark sandstone with scattered pebbles as above, passing down into loose sand with phosphatic pebbles including fish remains. Red chert and brown quartzite pebbles present, more abundant at base . .	15	515
Lower Carstone 30 feet.		
Ferruginous sandstone or sandy ironstone, with quartz slightly predominating over dark brown polished limonite ooliths [1]	6	521
Medium grained ferruginous sandstone, with light brown dull limonite ooliths in patches. Occasional pebbles of vein quartz and quartzite. In lower part light coloured and uncemented or dark and hard	15	536
Dull grey ferruginous sandstone and ironstone of quartz grains in a limonite or (rarely) glauconitic matrix. Some limonite ooliths, and a few glauconite and pyrite aggregates	9	545
Snettisham Clay 25 feet.		
Pinkish buff clay with dark brown limonite ooliths, containing a belemnite fragment	2	547
Pinkish, light grey, and greenish sandy clay (with quartz and dark limonite grains in a silty clay matrix) and clayey sand	4	551
Stiff light brown sandy clay with limonite grains . .	19	570
Sandringham Sands 133 feet.		
Coarse sand with some grains polished, others still showing crystal facies	7	577
Hard dark grey pyritic sandstone, and fine uncemented white sand (samples very badly contaminated below 599)	35	612
Light grey quartz sand, with much of the quartz faintly milky. Fine grained in upper 5 feet, medium grained below	45	657
Coarse and medium grained grey quartz sand, grades alternating in successive beds. Grains moderately well rounded	30	687
Brownish medium grained sandstone, slightly ferruginous .	10	697
Coarse grey sand (grains up to ¼ inch)	3	700
Fine-grained medium grey very hard pyritic calcareous sandstone with about 10 per cent of rounded glauconite grains	3	703

[1] Limonite grains usually showed an angular quartz grain as nucleus; in some cases a sub-rounded glauconite grain occurred instead.

The Carstone succession is notable for the sudden change of character 28 feet below the Red Chalk. Down to this level the sandstone is predominantly coarse and gritty, and includes irregular fragments of limonite concretions, phosphatic nodules and—especially at the base—quartz and quartzite pebbles Beneath this level the sandstone is uniform grained and contains limonite ooliths in such abundance that some parts could be described as iron ore. Conditions of deposition must have been very different during the deposition of the two sub-divisions of the Carstone, and the pebbly base of the upper division tends to emphasize other indications of a stratigraphical break.

At the base of the Carstone, on the other hand, there is a gradational junction with the Snettisham Clay. The latter is markedly sandy and contains limonite ooliths throughout, and it may be supposed that only a moderate increase in current velocities would be needed to produce the predominantly sandy facies of the later bed. On the evidence of this bore-hole section there is thus justification of assumption of continuous deposition between the later Neocomian and lower Aptian, with a non-sequence interrupting the Carstone succession.

These data have considerable bearing on the controversy which arose over the age of the Carstone. Kitchin and Pringle (1922, 1932) had concluded that there is essentially continuity between the upper Neocomian Snettisham Clay and the lower Aptian Carstone from palaeontological data, and the new evidence illustrates this further. They further suggested that the main Lower Aptian/Upper Albian break occurs at the base of the Red Chalk, but Rastall (1930) impressed by the petrological evidence of transition between this bed and the Carstone, argued that there was no significant break at this level, and that there was continuous deposition during the long period from the Lower Aptian. This concept was exceedingly difficult to reconcile with the coarse, even pebbly, character of the intervening unfossiliferous sandstone, which bears all the usual indications of rapid deposition.

The evidence from North Creake now suggests that transgressive Carstone of later Albian date—which may well be only slightly older than the Red Chalk—rests nonsequentially on Lower Aptian, the break dividing the bed into two nearly equal parts. The apparent restriction of the autochthonous Aptian fauna to the lower part of the Carstone at the outcrop further suggests that this correlation may be widespread in Norfolk.

A close analogy to this relationship is found on the opposite side of the Lower Cretaceous basin, in the northern part of the Lincolnshire Wolds, where very coarse current bedded Upper Carstone overlaps

a lower, fine-grained section in a relatively short distance. In Lincolnshire the relationship is complicated by the fact that an earlier part of the Carstone overlapped the basal Aptian and Neocomian towards the north, as Swinnerton (1935) showed, so that there is only a full sequence in the south of the Wolds. There is, in fact, evidence of both an Aptian and an Albian transgression within the Carstone of Lincolnshire, and the relation in Norfolk may eventually prove to be similar.

The Sandringham Sands were largely disintegrated in the course of drilling. During subsequent passage through the Jurassic clays there was a considerable amount of caving of clean quartz sand with well-preserved lamellibranch fragments (Pectinidae) which probably come from these beds. The lowest stratum of the subdivision was a hard pyritic calcareous sandstone with glauconite grains, virtually identical in appearance with the unweathered Spilsby Sandstone basement bed. The incoming of this at 700 feet provided a useful check on the position of the base of the sands, for otherwise there might have been a suspicion that caving was giving an exaggerated impression of their thickness.

3. *Kimeridge Clay* 160 feet

Dull grey-brown bituminous shale with *Lucina* ?	5	708
Dull grey clay	9	717
Pale grey shale and clay	6	723
Brownish grey bituminous shale with large shells	5	728
Dark blue grey clay	9	737
Brown bituminous shale and medium grey shale, some blue clay	16	753
Medium grey fissile shale	15	768
Bituminous and grey shale	5	773
Medium grey shale and clay with *Aptychi*	3	776
Light bluish grey shaly clay with nacreous shells	17	793
Medium grey shaly clay, with shell debris in lower part	15	808
Medum grey fissile shale crowded with iridescent shells, and subordinate brown fissile bituminous shale	5	813
Medium grey shale with scattered fossils including ammonites	5	818
Bluish grey shaly clay	15	833
Light-medium grey shaly clay with *Exogyra virgula* (Defr.) and *Aptychi*	15	848
Medium grey clay and shale. *Serpula* sp. aff. *tetragona* (Sow.)	5	853
Medium bluish grey shaly clay, with coarsely plicated Rhynchonella fragment probably *R. inconstans* (J. Sow.)	10	863

The presence of the probable *Rhactorhynchia* in the 853–8 sample provides useful supporting evidence of the position of the base of the division, which is mainly based on lithology.

The thickness of 160 feet compares with 145 feet at Southerey.

4. *Corallian* (*Ampthill Clay*) 85 feet

The Corallian clays do not differ greatly from those of the formations above and below. The upper boundary is fixed from the evidence

given above; the lower boundary at the base of the thick limestone, correlated with a similar bed forming the base of the Corallian at Southerey (Methwold Common) Boring as classified by Arkell (1936, plate iv). Very few fossils were found in the samples.

Bluish grey dark clunchy clay and shale	10	873
Lighter medium grey clay with nacreous shells, including fragments of Pectinids in the lower part	15	888
Dark rather sticky clay	5	893
Greenish grey shaly clay. Young *Astarte* ?	5	898
Dark and medium shaly clay, slightly pyritic	20	918
Dark grey hard shale with young *Ostreas*, and fragment of *Terebratula*	10	928
Blue grey pyritic shale (very dark when wet)	14	942
Hard medium grey limestone	6	948

The thickness of the formation is almost identical with that at Southerey.

5. *Oxford Clay* 138 feet

Like the Corallian above, the Oxford Clay was disappointingly unfossiliferous. No trace was found of the pyritized ammonites which are often abundant in the middle part.

Medium grey shale	10	958
Blue grey pyritic shale, nearly black when damp	15	973
Darker grey shale and medium grey limestone	5	978
Soft clay	23	1,001
Grey septarian limestone	2	1,003
Medium bluish grey shaly clay with *Ostrea* fragments	30	1,033
Dark grey shale and pale grey soft marly limestone	10	1,043
Medium grey pyritic clay and shale, with common *Ostrea*, rare *Gryphaea* and fish fragment	40	1,083
Dark grey slightly bituminous shale	3	1,086

The thickness (138 feet) compares with 157 feet at Southerey, where the Kellaways Beds are absent.

6. *Kellaways Beds* 46 feet

The Kellaways Beds are fully developed, and somewhat thickened as compared with the nearest outcrops. This may be due to approach to the London platform, but a comparable feature is not recognized further west.

Pale grey very fine calcareous sandstone, with a little sandy limestone (probably " doggers "). Samples included belemnite fragments, echinoid spine, *Ostrea* (one encrusted with *Serpula*), and a smooth cadicone ammonite which could be a very young *Cadoceras* of *sublaeve* type. Lower part shows filled worm borings	12	1,098
Grey and brownish sandstone and sandy limestone	17	1,115
Medium and dark grey shaly clay with *Ostrea* and iridescent shell fragments (Oxford Clay type of preservation). Fish tooth of *Hybodus* type	17	1,132

7. *Cornbrash* 6 feet

The Cornbrash is thin, and the lithological characteristics indicate that the upper subdivision only is present. No shell fragments were sufficiently large for specific identification.

Brownish grey finely crystalline limestone, with common shell fragments. *Ostrea*, etc.	6	1,138

8. *Blisworth Clay* 58 feet

Below the Cornbrash almost no cuttings other than small quantities of cavings were collected for 40 feet, and it seems that this interval must be almost entirely soft clay. A little lower down grey shale yielded *Ostrea* cf. *subrugulosa* Mor. and Lyc., establishing the Blisworth Clay age of the division.

Soft clay, with a little grey shale and brownish limestone in the middle part	40	1,178
Dark grey and buff shale, with common *Ostrea* fragments including *O.* cf. *subrugulosa*	18	1,196

This formation is considerably expanded in thickness as compared with the outcrop. The clay development at this horizon contrasts with the Forest Marble of Southerey, and shows that in Norfolk, as in the South Midlands, there is a passage into a limestone facies towards the edge of the basin. The line of demarcation of the two facies thus runs north of Bicester and Calvert, south of Bletchley and Bedford, north of Southerey and south of North Creake—a nearly north-east–south-west line.

9. *Great Oolite Limestones* 39 feet

The Great Oolite Limestones were crystalline and raggy, and practically free from oolite. In this they resemble the Lincolnshire rather than the South Midland development.

Medium or light brownish grey finely crystalline hard impure limestone with a little dark shale. *Ostrea* fragment, indeterminate, could be *sowerbyi* (not ribbed)	12	1,208
Light grey finely crystalline uniform limestone, rare echinoderm fragments in lower part	10	1,218
Grey raggy limestone, crowded with shells, probably *Ostrea*	17	1,235

A single chip of oolitic limestone found in the 1218–1223 sample may be accidental contamination, but if so it is not clear whence it may have come.

10. *Upper Lias* 41 feet

The Great Oolite proves to be markedly transgressive as is usual round the Ardennes-London massif. The beds beneath include a very thick development of bituminous shale which cannot be matched in any English Inferior Oolite development, and which is presumed to be a rich development of the lower Upper Lias papershales, which

are moderately bituminous at outcrop. Unfortunately the cuttings were unfossiliferous.

Dark brown bituminous shale, finely laminated in lower part, with a little interbedded grey shale	26	1,261
Grey shale and light grey shaly clay	15	1,276

11. *Middle Lias* 77 feet

At 1,276 feet the well encountered hard beds in which fine sandstones predominated. A coarsely punctate *Terebratula* was present in some quantity (fragments only were recoverable because of the drilling method) and *Rhynchonella* also occurred. From these characters the bed is identified as the Middle Lias " Marlstone " with *Lobothyris punctata* (J. Sow.) and " *Rhynchonella tetrahedra* " auctt., although it presents a marked lithological contrast to the oolitic ironstone of the Midlands outcrop and is equally unlike the marly and clayey limestone of Southerey (Severals House boring). The thin streak of oolitic ironstone at the top is, however, reminiscent of a bed in this position in the Sproxton boring.

Marlstone	Trace of buff ironstone with white ooliths, non-calcareous	¼	1,276¼
	Light grey fine calcareous sandstone, micaceous	6¾	1,283
	Brownish micaceous calcareous sandstone with shelly material	8	1,291
	Grey raggy sandy limestone with *Rhynchonella*, common *Terebratula*, and *Serpula*	7	1,298
	Medium grained grey micaceous sandstone and sandy limestone with common ? *Pseudopecten*	5	1,303
	Light grey thinly bedded micaceous sandstone with traces of echinoidal limestone. *Ostrea*, *Protocardium* ?, *Terebratula*, and *Belemnites*	12	1,315
Clays	Light grey shale with ironstone nodules	23	1,338
	Soft light grey clay with a little darker shale	15	1,353

The position of the base of the subdivision is taken by analogy with Southerey, at the base of light grey clays and above dark shales. At Southerey (Severals House Boring), *Amaltheus* occurs just above this change, and *Androgynoceras lataecosta* just below.

12. *Lower Lias* 423 feet

The Lower Lias yielded fewer diagnostic fossils than might have been expected, and the tentative classification is based mainly on the lithological characters as compared with the outcrops of South Lincolnshire and Leicestershire.

Zones.			
davoei and *ibex* 50 ?	Dark grey shale with a trace of limestone. *Ostrea*, *Pentacrinus*, and pyritized *Natica*	18	1,371
	Brownish ferruginous limestone and dark grey shale	32	1,403
jamesoni and *raricostatum*	Dark grey thinly bedded shale with light grey argillaceous limestone bands and some brownish clay ironstone	15	1,418

Zones			
55 ?	Grey clay with nodules of purplish clay ironstone and light grey cementstone . . .	40	1,458
oxynotum, *obtusum*,	Medium grey shale with greenish or yellowish brown ironstone nodules	50	1,508
and *turneri* 120 ?	Grey shale with reddish ironstone nodules, *Ostrea* and fragment of ammonites . .	20	1,528
	Soft clays (mainly washed away) with *Astarte* ? and ammonite	50	1,578
semicostatum 20 ?	Medium grey shale with subordinate argillaceous limestone. *Ostrea*, *Gryphaea* . . .	20	1,598
bucklandi	Dark grey fairly hard shale. *Ostrea* . .	40	1,638
and	Blue grey shale	40	1,678
angulatum 150 ?	Dark blue grey shale with bands of light grey argillaceous limestone	60	1,738
	Blue grey shale, dark when wetted, with very little limestone	10	1,748
planorbis 28 ?	Blue grey shale with light brownish finely crystalline limestone	28	1,776

In this classification the shales with limestone at 1578–1598 are equated with the Ferruginous Limestone group of North Leicestershire, and the thicker group with a larger proportion of stone at 1678–1738 with the *angulatum-bucklandi* limestones of the same area.

13. *Rhaetic* ? 14 feet

At 1776 there is a marked change from typical Liassic shale and limestone to dull brown and dark grey shale without calcareous bands. This has not the fine lamination of typical Rhaetic material, but it is so unlike ordinary Lias that it is ascribed provisionally to the Rhaetic. No fossils could be detected in the cuttings.

Dull brown shale	2	1,778
Dull dark grey shale, practically black when damp, and medium bluish grey smooth shale	12	1,790

All this material may be Lower Rhaetic (Westbury Beds).

14. *Keuper* 513 feet

The position of the top of the Keuper was indicated by a change in drilling speed ; Keuper material first appeared in the samples at 1,800 feet.

Pale green silty clay	15	1,805
Very fine grained grey sandstone	3	1,808
Mottled red-brown and green sandy silt with scattered yellow quartz grains	12	1,820
Reddish silty marl, with white sugary gypsum	30	1,850
Reddish silty clay and grey green shaly clay ; the latter becoming predominant in the lower part	40	1,890
Deep red and brick red silty marl with sugary and fibrous gypsum veins (occasionally slickensided) with a streak of fine greenish sandstone 85 feet down	190	2,080
Red and greenish mottled marl, with a streak of light grey medium grained sandstone 30 feet down	155	2,235
Red and greenish mottled shaly clay and marl, interbedded with light brown fine to medium grained sandstone . .	68	2,303

In this succession the uppermost stratum might possibly represent the Tea Green Marls, but this is by no means certain as the Rhaetic or Lias transgression would probably involve conditions capable of reducing the uppermost Keuper regardless of its age.

The lowest marls, which are more shaly and are interbedded with sandstones, recall the Keuper Waterstones of the Midlands.

15. *Bunter* 132 feet

Predominantly a white, medium grained quartz sandstone, with subangular grains. Occasional larger grains nearly sphaerical, scattered vein quartz pebbles present throughout. Most commonly very porous, sometimes kaolinitic, occasionally dense. Pyrite crystals locally cement sand grains. Twenty feet down is a fine greenish sandstone, 60 to 80 feet down the sandstone is partly buff or pale brown, otherwise it is homogeneous. No evidence of pebbly base . . .	132	2,435

On sample evidence the base might be as much as 20 feet lower; the above reading is based on drilling characteristics, it being supposed that the upper part of the Pre-Cambrian rock was weathered and failed to produce cuttings.

The whiteness of the sandstone contrasts with the usual appearance of the bed near outcrop. In this and in the presence of a greenish stratum it resembles Keuper Basement Beds more than typical Bunter, although greenish shale occurs occasionally in the Bunter of Nottinghamshire, and white sandstone is well developed at this horizon in Derbyshire. The absence of beds made up of rounded grains distinguishes it from Keuper Basement Beds as developed, for example at Formby (Lancashire). The facies is entirely characteristic of aqueous deposition, and the bed is provisionally regarded as equivalent to the Bunter Pebble Beds.

16. *Pre-Cambrian*

From the Bunter the borehole passed directly into Pre-Cambrian rock. This was a dark greenish grey somewhat sheared tuff of Charnian type. The 197 feet penetrated appeared to be all of this kind and a hardening of the lowest part was not accompanied by any visible change. Dr. James Phemister made the following report on this rock :—

" The core samples from North Creake No. 1 B.H. at 2,491 feet and 2,494–5 feet are of rock which matches well with the Charnian agglomerate or tuff found at Whitwick, Forest Rock, and Bardon Hill in Leicestershire. Microscopically the samples show rock of varying composition. In part it is formed of fine sericitic and chloritic matrix speckled with epidote and carrying numerous fragments and corroded crystals of quartz and numerous sericitized and epidotized

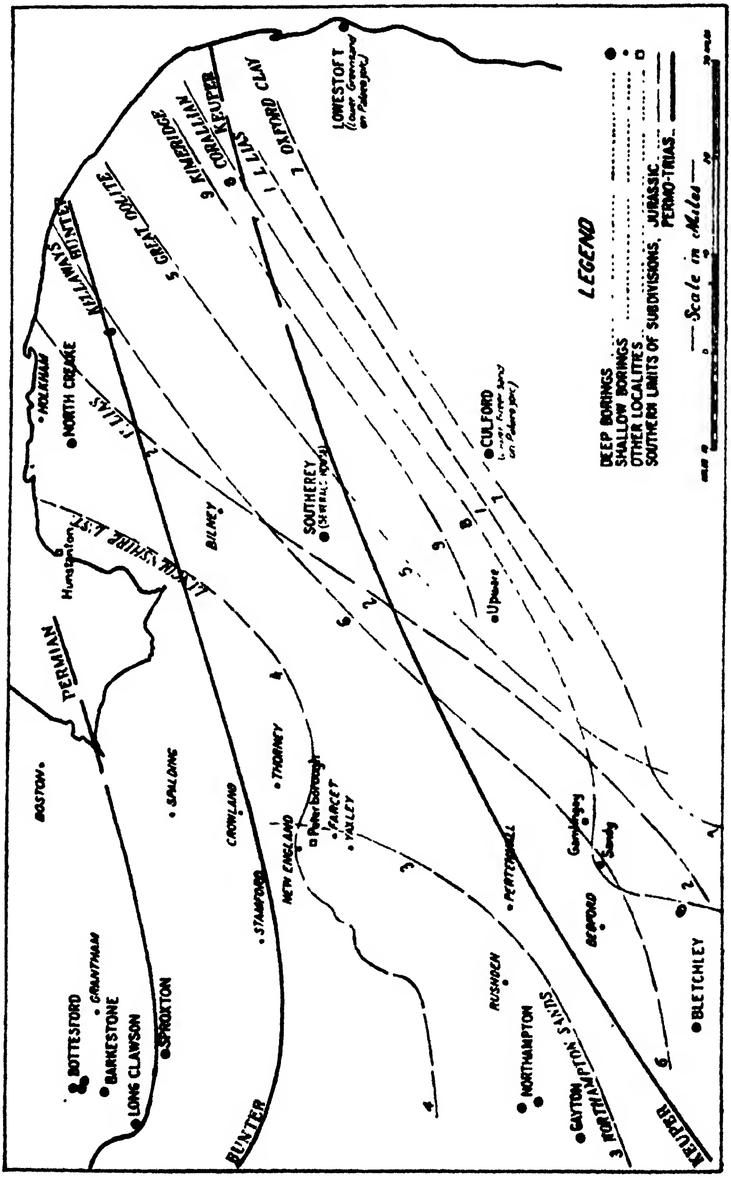
crystals of oligoclase. In other parts the matrix is more richly chloritic and carries feldspar crystals and chlorite pseudomorphs after some mafic constituent, but contains little quartz. The more richly chloritic portions are usually indefinitely bounded from the more sericitic matrix, but in the specimen from 2,491 feet (Geol. Surv. No. E 20879) two chloritic patches have well defined margins and the structures within them suggest that they represent sub-basic fluidal lavas. In the other specimen (E. 20880) a richly chloritic patch contains numérous feldspar phenocrysts, turbid but not epidotized, and carbonate clots after a mafic constituent, but no quartz. In this case the boundaries of the patch are quite irregular and interpenetrate with the main matrix, so that if the patch represents a pyroclastic fragment, as seems to be the case from its distinctive constitution, its original shape has been destroyed. In both rocks there are some signs of schistosity, for example, sericite and chlorite flakes are disposed in parallel orientation especially in restricted spaces between large mineral fragments, but on the whole schistosity is not pronounced. The appearance of foliation in hand specimen seems to be due to the parallel disposition of the chloritic patches and long crystals of feldspar. This structure may be original, but in view of the local reorientation of the matrix constituents, it is probable that some rearrangement under stress has taken place.

" The rocks resemble the aforementioned Charnian types in (1) the heterogeneous composition and the nature of the diversity from quartz-rich portions to feldspar- and chlorite-rich portions, (2) the partly fragmental, partly corroded porphyritic characters of the quartz, (3) the frequency of epidote in feldspar crystals and in the matrix, and (4) the very fine grained sericitic, chloritic, and epidotic character of the matrix."

The South-Eastern Limits of the Mesozoic Rocks

With North Creake as a new control point, it is possible for the first time to indicate the limits of the Mesozoic formations on the northern side of the London-Ardennes " platform " (Text-fig. 1).

The first of the post-Variscan formations is the Permian. Deep borings for oil drilled by the D'Arcy Exploration Company further west have shown that the Magnesian Limestone thins out on an east–west line through Nottingham, so that it is present at Bottesford but absent at Barkestone (Lees & Taitt, 1946). A gypsiferous marl facies, however, extends further south (200 feet thick at Barkestone, 30 feet thick at Long Clawson), but this also is absent at Sproxton, and no Permian representative is recognizable at North Creake. From these data, and taking account also of the nearly east–west trend of the



TEXT-FIG. 1.—The Probable South-Eastern Limits of Buried Mesozoic Rocks in East Anglia.

Permian isopachytes between Grantham, Lincoln, and Stixwould, it is considered that the formation is overlapped along a line which trends east-by-north from near Sproxton to the Wash, a line which passes close to Hunstanton.

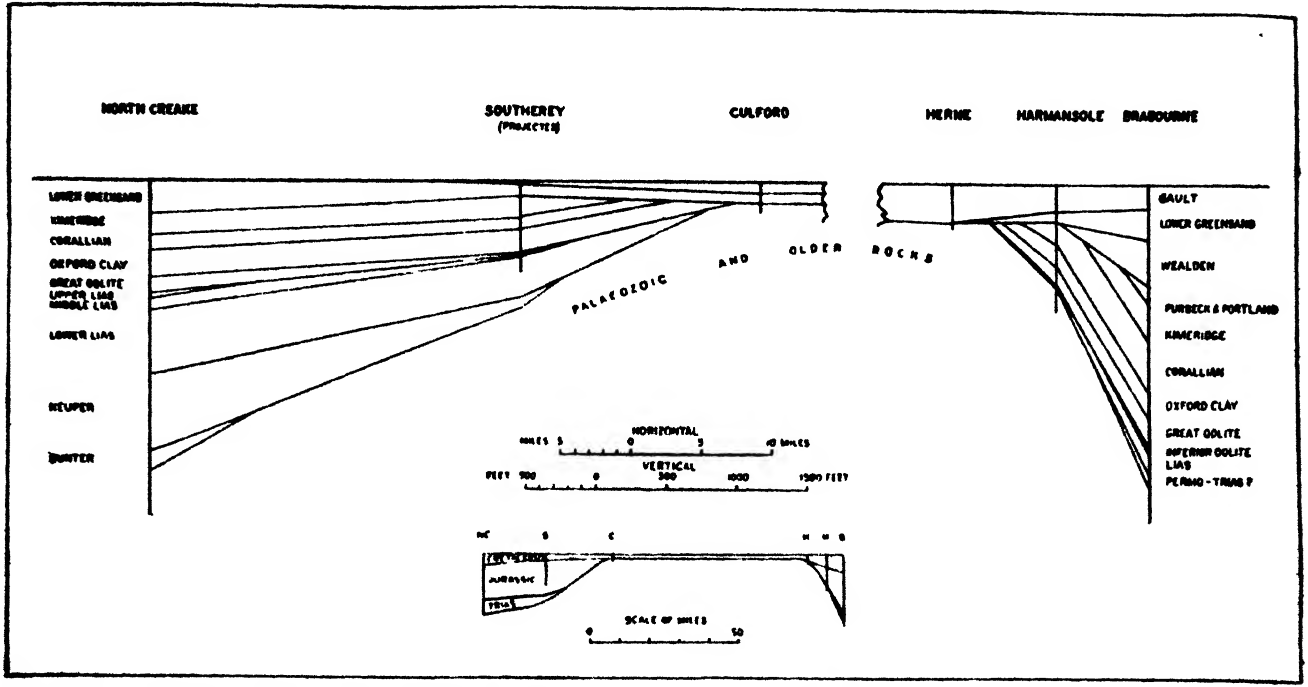
In the Central Midlands the Trias extends far south of the Permian so that thin Keuper is present in Northamptonshire, although it is absent at Calvert and Bletchley twenty miles further south. The North Creake boring proved Trias of such thickness that the locality is evidently well north of the featheredge of the formation, and the limit may be supposed to trend approximately E.N.E. from Southern Northamptonshire to the Norfolk coast. On the accompanying map it is drawn about 15 miles north of Culford and Lowestoft. The lower member—the Bunter—is somewhat attenuated at North Creake, and is probably overlapped some few miles south of there, the Keuper transgressing beyond it across the Palaeozoic floor, as in the country further west.

The Rhaetic is very thin at North Creake—if indeed it is really present—and it is probably absent, overlapped by the Lias, over the country to the east and south. This implies slight post-Triassic tilting.

The earlier Jurassic beds were, in the main, deposited in conformable sequence. Although they are thinning southwards, their southward extent is in nearly every case determined by truncation by the Great Oolite Series, which transgressed after the most important phase of intra-Jurassic tilting known in the East Midlands—tilting which had its precise analogue in Kent, and is clearly due to a gentle upwarping of the " London Platform ". In mid-Lincolnshire the Inferior Oolite sequence is nearly complete, with a thick development of Middle and some Upper Inferior Oolite locally present, in South Lincolnshire the Inferior Oolite Limestone is thinning out (with an intra-Inferior Oolite unconformity as a complicating feature) and the lowest beds are overstepped at Kettering and near Peterborough. South of this the " Northampton Sands " disappear (with both Great Oolite overstep and approach to the contemporary shoreline as factors), at North Creake the greater part of the Upper Lias has also gone, and at Southerey Middle and Lower Lias alone remain.

The plane of erosion may well have truncated the Lower Lias and reached the Palaeozoic floor beyond this, but it is doubtful whether the Great Oolite itself extended so far, for it has already become attenuated by loss of its lower members at Southerey, and it may never have spread much further.

The Kellaways period marked a temporary regression, for these beds do not extend as far as the Great Oolite either in Bedfordshire or at Southerey. In so far as the Kellaways Beds are of normal thickness as far south as Bedford it seems probable that their absence is



TEXT-FIG. 2.—Diagram showing the Relationship of the Mesozoic Rocks to the Palaeozoic Platform in East Anglia and Kent. The smaller diagram shows the northern and southern sections in their correct horizontal relationship.

partly due to subsequent erosion, and the occasional absence of the Cornbrash south of the limits of the Kellaways beds emphasizes the probability of erosion as a factor. On the other hand, the sandy facies is itself evidence of a widespread positive movement during Kellaways times.

In Oxford Clay times deposition extended again further south. The proved thickness in Norfolk is only half as great as in mid-Lincolnshire, and at Southerey Arkell (1936) has shown that the uppermost and lowermost zones are missing or extremely thin. Nevertheless the formation must have extended nearly as far south as Culford. The Corallian and Kimeridge are similarly reduced as compared with Central Lincolnshire, but they do not appear to be thinning very quickly in West Norfolk. There seems no evidence of overstep within the succession, and the uniform clay facies does not suggest proximity of a shoreline.[1] Their south-easterly extension is presumably controlled by pre-Aptian uplift and erosion (as around Leighton Buzzard and Sandy), so that the Kimeridge will be overstepped first, the Corallian next, and the Oxfordian extend furthest south. On the map it is assumed that the Oxfordian oversteps the Lower Lias and comes to rest directly on the Palaeozoic floor as in the London district ; whether this is the correct assumption could only be determined by drilling. It is possible that the Trias extends further than the Lias near the Norfolk coast—a relationship envisaged by Arkell in Devonshire (1933, fig. 94)—and that the Oxford Clay rests directly upon it.

The latest formation to share the overlapping relation to the Palaeozoic "platform" is the Neocomian, which is restricted to North-West Norfolk. The available information points to nearly perfect parallelism between this formation and the underlying Kimeridge, despite the absence of the Portland and Purbeck formations. It follows that the transgression was not preceded by tilting similar to that which occurred at earlier periods. The Neocomian beds themselves, however, appear to be truncated obliquely, for the Snettisham Clay does not extend further south than Kings Lynn, and it seems that the Sandringham Sands are progressively overstepped south of this. The transgressive series above involves Aptian Greensand, Gault, and the Chalk, which spread as a conformable unit (although not without non-sequences) over the entire stable area, linking the Midlands and South until the end of the Mesozoic period.

[1] The occurrence of a limestone facies of Corallian at Upware may, however, be significant. It is possible that this provides an indication of the normal condition south-east of the available borings—that there may have been a fringing reef on the northern side of the stable "platform" of which this is the only portion exposed.

Summary

1. The North Creake boring shows the Chalk up to the Coranguinum zone to be appreciably thicker than at the nearest outcrops. The Chalk rests upon fine-grained Upper Greensand (possibly Albian) which is developed in addition to the normal Red Chalk.

2. The " Lower Greensand " is developed much as at outcrop, but the Sandringham Sands are thickened by one-third. There is a strong indication of a stratigraphical break in the middle of the Carstone, which may mark the boundary between the Aptian and Albian stages.

3. The Kimeridge, Corallian (Ampthill), and Oxford Clays are developed as in the King's Lynn district, and (in contrast to Southerey) normal Kellaways Beds rest on Cornbrash.

4. The upper part of the Great Oolite Series is in Blisworth Clay facies. The " Limestone " is raggy and non-oolitic.

5. The Great Oolite rests directly on bituminous shales which are believed to be of early Upper Lias date. The Middle and Lower Lias are well developed, but the latter is attenuated as a whole. There is a possible representative of the Lower Rhaetic.

6. The Trias is represented by varicoloured marls (Keuper) upon pale grey sandstone (probably Bunter). The latter rests directly on pre-Cambrian rocks comparable with tuffs and agglomerates of Charnwood.

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The Granitic Cotectic Curve

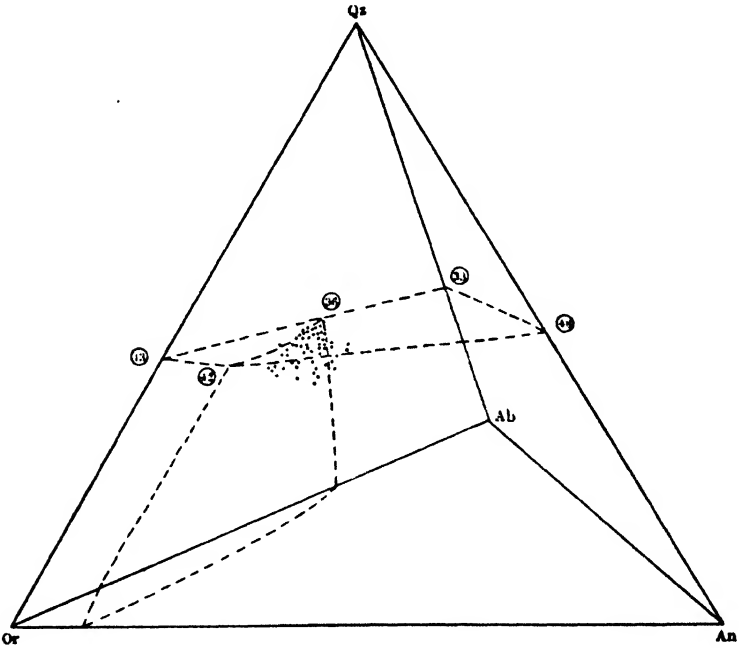
By S. R. Nockolds

In a recent paper (Nockolds, 1946) it was shown that certain granite-aplites associated with acid plutonic rocks of Caledonian age in Western Scotland fell on, or were very close to, the plagioclase-potash felspar-quartz cotectic curve (the granitic cotectic curve), the approximate position of which could be determined from experimental data now available. It seemed of interest to determine whether other granite-aplites from other areas behaved in the same way and chemical analyses of granite-aplites and related rocks were collected from the literature with this end in view.

Some of the older analyses of granite-aplites, where there was reason to doubt the accuracy of the alkali determinations, and all analyses showing an appreciable amount of normative corundum, indicating the presence of muscovite or of alteration, were discarded and only those analyses used whose contents of SiO_2, Al_2O_3, CaO, Na_2O, and K_2O would, on recalculation, give with a reasonable degree of accuracy the percentages of quartz, anorthite, albite, and orthoclase occurring in the rock. Putting aside certain potash-rich and soda-rich aplites which will be considered later, sixty-three analyses of aplites, aplitic granites, and related rocks were available for study.

Most petrologists regard such rocks as representing residual magmas and, if this view is correct, then these rocks should show a more or less close degree of approach to the plagioclase-potash felspar-quartz cotectic curve. But although these aplites represent residual liquids from granitic magmas it does not follow that the whole of their crystallization took place along the ternary cotectic curve, i.e. that their composition represents a point on that curve. Text-fig. 1 shows the sixty-three aplites and related rocks plotted in the four-component system quartz-anorthite-albite-orthoclase. It will be noticed that many of them lie in the plagioclase field approaching more or less closely the plagioclase-quartz boundary surface or the ternary cotectic curve. The important point is that none of them lie in the orthoclase field or the quartz field or on the orthoclase-quartz boundary surface. This is what we should expect if the aplites represent residual liquids derived from more basic granitic or granodioritic magmas. Moreover, twenty-five out of the sixty-three analyses fall on, or lie close to, the ternary cotectic curve and these can be taken as giving, at least approximately, the composition of mixtures at various points on the ternary cotectic curve. The percentages of quartz, orthoclase, albite, and anorthite for these twenty-five rocks are given in Table I, where the rocks are arranged in order of increasing Or : Ab + An ratio. Text-fig. 2 shows these rocks plotted in the four-component

system with the ternary cotectic curve indicated as a dotted line, while Text-fig. 3 is the same diagram now given as a projection on the base of the tetrahedron. The ratio Or : Ab + An ranges from 41 : 59 to 57 : 43, no aplites lying on the cotectic curve having been found with a higher ratio than the latter, although it is quite possible that such may exist. The ternary eutectic Or : Ab : SiO_2 was taken as being

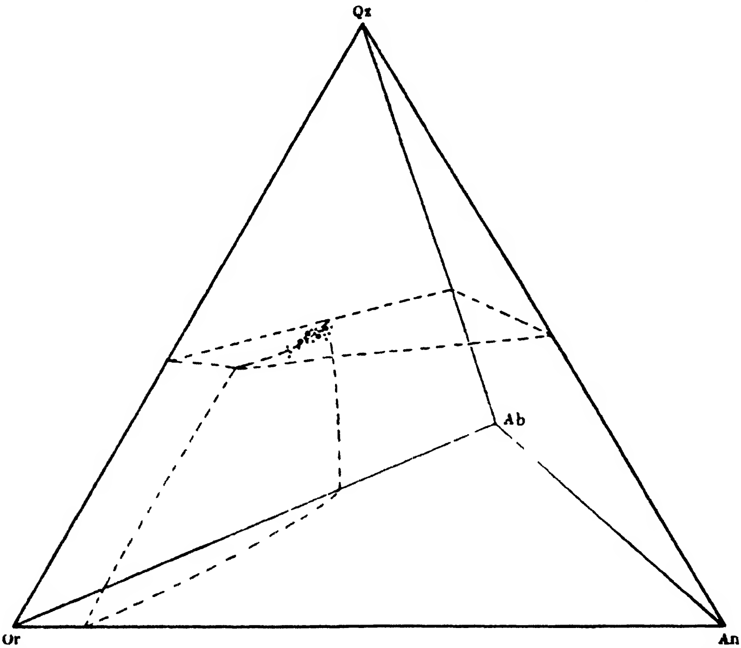


TEXT-FIG. 1.—Perspective diagram of the system quartz-anorthite-albite-orthoclase, showing the potash felspar-plagioclase, quartz-plagioclase, and quartz-potash felspar boundary surfaces and the plagioclase-potash felspar-quartz cotectic curve (see Nockolds, 1946). The bulk compositions of sixty-three aplites in terms of the four components have been plotted in the diagram. They lie in the plagioclase field ; close to, or on, the plagioclase-quartz boundary surface ; or close to, or on, the plagioclase-potash felspar-quartz cotectic curve. Some of the points represent more than one analysis, but, in order to avoid overcrowding, these points have not been made larger than the others. The figures in circles give the percentage of quartz at various points.

of composition Or 28 : Ab 36 : SiO_2 36 in the paper referred to above (Nockolds, 1946), but at least as far as the natural rocks are concerned, it would appear that this eutectic must be somewhat richer in albite and lie at a composition close to Or 25 : Ab 39 : SiO_2 36, giving an Or : Ab ratio of 39 : 61. This composition has been taken as that

of the ternary eutectic Or : Ab : SiO_2 in the text-figures accompanying this paper.

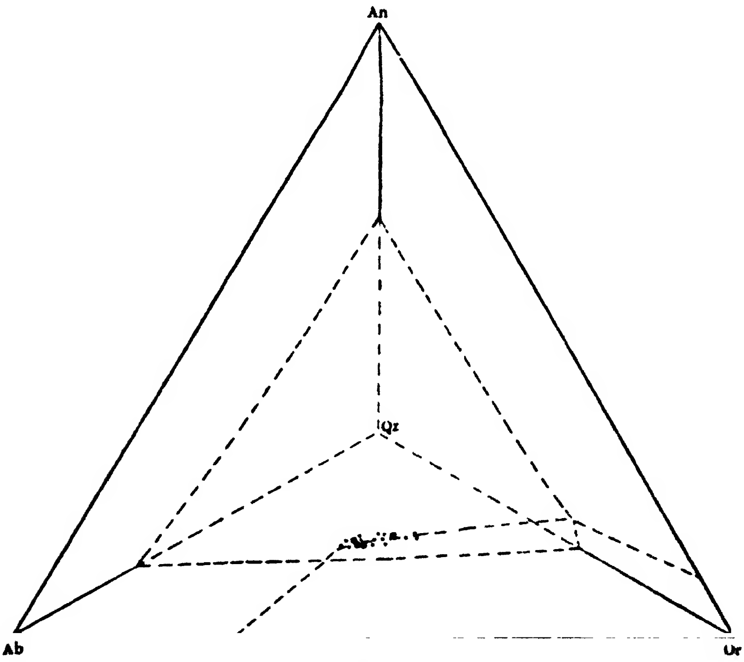
J. H. L. Vogt devoted a considerable amount of time to the determination of what he termed the ternary granitic eutectic, and the fullest expression of his results is to be found in a monograph published in 1931 (Vogt, 1931). From a detailed consideration of the groundmass composition of rhyolites, quartz-porphyries, etc., and a study of the granite-aplites, he reached the conclusion that the ternary



TEXT-FIG. 2.—The same diagram as Text-fig. 1, showing the positions of those aplites whose composition is such that they lie on, or very close to, the ternary " granitic " cotectic curve. Large dots indicate that two analyses occupy the same position.

eutectic would have about 75 per cent SiO_2 and a ratio of Or : Ab (+ An) of about 40 : 60. According to his calculations this would give about 32 to 33 per cent of quartz and 68 to 67 per cent of felspar. Vogt's ratio of Or : Ab (+ An) = 40 : 60 is, indeed, closely approached near the albite end of the ternary cotectic curve, but the percentage of quartz is greater than he estimated. He was, of course, well aware that his " ternary granitic eutectic " was not a fixed point but a granitic cotectic curve. When, however, he considered the composition of rocks lying at positions richer in orthoclase, for example 50 Or : 50 Ab (+ An), he estimated that they would

have a lower percentage of quartz than those richer in albite (about 28 per cent for the example given) (Vogt, 1931, 154). Actually, as the figures in Table I indicate, the percentage of quartz tends to rise as the amount of orthoclase increases with respect to albite and this is what would be expected from the experimental data. Probably the main reason for these discrepancies is that Vogt, in dealing with granite-aplites as a whole and with the groundmasses of quartz-porphyries, etc., was not dealing only with compositions which lay on the ternary cotectic curve but also with a number of others which were more or less distant from this curve.



TEXT-FIG. 3.—Projection of Text-fig. 2 on the base of the tetrahedron.

The fact that many granite-aplites and related rocks lie on, or close to, the plagioclase-potash felspar-quartz cotectic curve, and that the remainder lie in the plagioclase field and on, or close to, the plagioclase-quartz boundary surface, seems to the writer to have an important bearing on their origin. It is consistent with the generally accepted view that they represent residual liquids derived by crystallization-differentiation from a more basic magma and it would also be consistent with the view that they were products of refusion, representing the lowest melting mixtures, if any evidence of such refusion should

TABLE I

	1	2	3	4	5	6	7	8	9	10	11	12	13
qz .	37	39	36	37	39	39	39	38	37	37	36	38	39
or .	26	25	27	27	26	26	27	27	28	28	28	28	28
ab .	34	33	34	33	32	31	31	33	32	32	33	32	31
an .	3	3	3	3	3	4	3	2	3	3	3	2	2
Ratio or: ab + an	41 : 59	41 : 59	42 : 58	43 : 57	43 : 57	43 : 57	44 : 56	44 : 56	44 : 56	44 : 56	44 : 56	45 : 55	46 : 54

	14	15	16	17	18	19	20	21	22	23	24	25
qz . .	39	40	37	39	39	36·5	40	39	39	37	36	39
or . .	29	29	30	30	30	32	30	31	31	34	35	35
ab . .	29	28	31	28	27	29	26	26	26	26	24	23
an . .	3	3	2	3	4	2·5	4	4	4	3	5	3
Ratio or: ab + an.	47 : 53	48 : 52	48 : 52	49 : 51	49 : 51	50 : 50	50 : 50	51 : 49	51 : 49	54 : 46	55 : 45	57 : 43

NOTES TO TABLE I

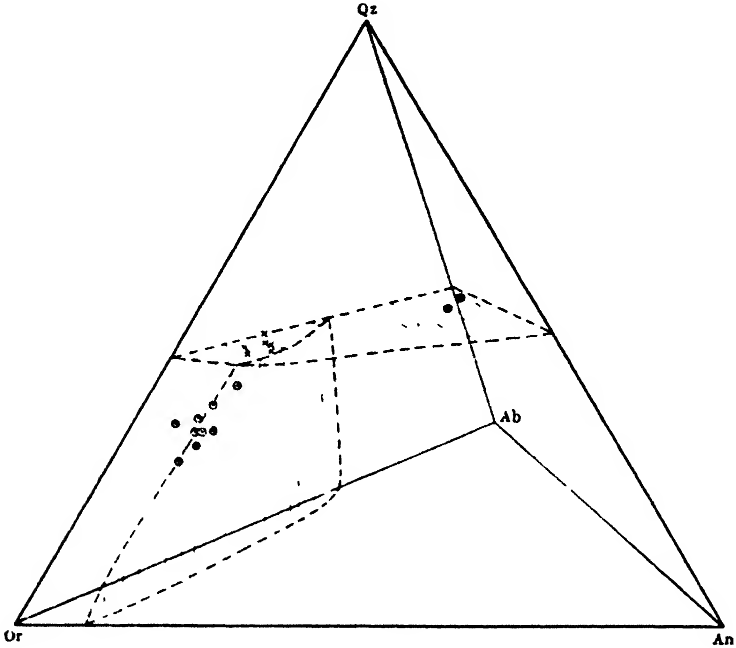
1. Aplite, Jagihorn, Aar Massif, Switzerland (W. Minder, *Schweiz Min. Petr. Mitt.*, 14, 1934, 155).
2. Aplite, Dauphiny, France (P. Termier, *Bull. Soc. Géol. France*, 27, 1899, 404).
3. Aplite, cutting Rätan granite, Loos-Hamra region, Sweden (H. v. Eckermann, *Geol. Fören. Stockholm Forhandl.*, 58, 1936, 263).
4. Granite, Bear Mt., Gillespie Co., Central Texas (S. S. Goldich, *Jour. Geol.*, 49, 1941, 706).
5. Aplite, Tandjong-Sakti road, S. Sumatra (A. Lacroix, *Bull. Soc. franc. Min.*, 55, 1932, 179).
6. Aplite, Saganeiti, Eritrea (H. S. Washington, *U.S.G.S. Prof. Paper*, 99, 1917, 71).
7. Aplite, Port Manvers, Labrador Coast (F. F. Grout, *Jour. Geol.*, 46, 1938, 496).
8. Aplite, Baveno, Italy (P. Niggli, *Schweiz Min. Petr. Mitt.*, 2, 1922, 173).
9. Aplite, Garabal Hill-Glen Fyne complex, Argyllshire, Scotland (S. R. Nockolds and R. L. Mitchell, *Trans. Roy. Soc. Edin.*, in the press).
10. Aplite, Old quarries, Loch Awe, Scotland (S. R. Nockolds and R. L. Mitchell, *Trans. Roy. Soc. Edin.*, in the press).
11. Rhyolite, Glen Coe, Scotland (*Geology of Ben Nevis and Glen Coe, Mem. Geol. Surv. Scot.*, 1916, 182).
12. Quartz-felspar-porphyry, Glasdrumman Port, N. Ireland (S. I. Tomkeieff and C. E. Marshall, *Quart. Journ. Geol. Soc.*, 91, 1935, 267).
13. Acid rapakivi granite, Loberget, Loos-Hamra region, Sweden (H. v. Eckermann, *Geol. Fören. Stockholm Förhandl.*, 58, 1936, 294).
14. Rhyolite, Sheridan volcano, Yellowstone district, U.S.A. (F. W. Clarke, *U.S.G.S., Bull.* 591, 1915, 87).
15. Granite, Newcastle, Co. Down, N. Ireland (S. R. Nockolds and J. E. Richey, *Amer. Jour. Sci.*, 237, 1939, 41).

16. Aplite, Naversnes, Stavanger, Norway (V. M. Goldschmidt, *Videnskaps. Skrift. I. Mat-nat. Kl.*, Kristiania, 1920, No. 10, 30).
17. Granite, Sentinel Point, Pikes Peak, Colorado (E. B. Mathews, *Jour. Geol.*, 8, 1900, 237).
18. Aplite, Traversella, Piedmont, Italy (W. Q. Kennedy, *Schweiz Min. Petr. Mitt.*, 11, 1931, 91).
19. Quartz-porphyry, Glen Etive, Scotland (*Geology of Ben Nevis and Glen Coe, Mem. Geol. Surv. Scot.*, 1916, 182).
20. Granite, Pyramid Peak, Eldorado County, California (W. Lindgren, *Amer. Jour. Sci.* (4), 3, 1897, 306).
21. Aplitic granite, Cove River, Bowenfels, New South Wales (H. S. Washington, *U.S.G.S. Prof. Paper*, 99, 1917, 71).
22. Aplite (average of two analyses), Ukua Parish, Skrikerum, Sweden (N. Sundius, *Sver. Geol. Undersök*, Ser. C., 336, 1926, 15).
23. Aplite, Garabal Hill-Glen Fyne complex, Argyllshire, Scotland (S. R. Nockolds and R. L. Mitchell, *Trans. Roy. Soc. Edin.*, in the press).
24. Aplite, Garabal Hill-Glen Fyne complex, Argyllshire, Scotland (S. R. Nockolds and R. L. Mitchell, *Trans. Roy. Soc. Edin.*, in the press).
25. Aplite (average of two analyses), Nettie Mine, Butte, Montana (W. H. Weed, *Jour. Geol.*, 7, 1899, 739).

come to hand. But it does not appear to be consistent with the view that they have been derived directly or indirectly from the activity of emanations acting on sedimentary or other rocks. Why should the products of such activity tend towards a plagioclase-potash felspar-quartz cotectic curve which, as we have seen, can be deduced from available experimental data on dry melt systems depending on crystal $\rightarrow$ melt equilibria ?

There are certain granite-aplites considerably richer in potash than any of those yet dealt with. Some of these are relatively rich in muscovite, owe their increased richness in potash to this cause, and so do not concern us further. But a few have been found where the richness in potash is due to the presence of considerable amounts of orthoclase (Table II, cols. 1 to 6). Such rocks do not lie on the ternary cotectic curve but lie on, or very close to, the potash felspar-quartz boundary surface (Text-fig. 4). It is interesting to observe that these aberrant potash-aplites are associated with parental granitic rocks which carry muscovite as well as biotite in all cases where the associated rocks are known. It was found previously that granitic rocks carrying muscovite did not fall on the normal crystallization curve for the Caledonian igneous rocks of Western Scotland, but were marked by their comparative richness in quartz (Nockolds, 1946, 214). The same feature is shown by those muscovite-biotite granites from Dartmoor for which the modes are known (Brammall and Harwood, 1932). It appears that the crystallization of primary muscovite upsets the normal equilibrium of the magma with the result that a different residual magma may be generated. The conditions are too complex to be evaluated at the present time, but it is conceivable that the relatively early crystallization of muscovite, a mineral with a low

content of silica compared to felspar, allows the liquid to leave the plagioclase-quartz boundary surface once it has been reached, owing to the relatively greater amount of silica left in the residual liquid. If this did occur, then the course of crystallization of the residual liquid could cross the field of quartz and reach the potash felspar-quartz boundary surface from which it might, or might not, finally



TEXT-FIG. 4.—Perspective diagram of the system quartz-anorthite-albite-orthoclase showing (*a*) the positions of the potash-rich aplites, marked by crosses, lying on, or very close to, the potash felspar-quartz boundary surface; (*b*) the positions of the graphic intergrowths of plagioclase and quartz from granite-pegmatites, marked by large dots, lying on the plagioclase-quartz boundary surface; (*c*) the positions of the graphic intergrowths of potash felspar and quartz from granite-pegmatites, marked by ringed dots, lying in the potash felspar field.

pass down to the ternary cotectic curve. The real picture is more complex because we are dealing here only with the projection of a natural magma out of the polycomponent system to which it belongs into a four component one. Alternatively, these potash-aplites may be produced from ordinary granite-aplites by some process of potash metasomatism.

Another rarer type of granite-aplite is one in which all the felspar

TABLE II

	1	2	3	4	5	6	7	8	9	10
qz .	38	38	40	39	39	41	32	30	41	39
or .	37	38	42	38	42	38	3	3	2	tr.
ab .	23	21	17	21	17	20	63	66	52	60
an .	2	3	1	2	2	1	2	1	5	1

NOTES TO TABLE II

1. Aplite, Encounter Bay, S. Australia (W. R. Browne, *Trans. Roy. Soc. S. Australia*, 44, 1920, 26).
2. Aplite, Ocna de Fer, Banat, Roumania (A. Codarcea, *Ann. Inst. Géol. Romaniei*, 15, 1930, 339).
3. Granite, Stewart Island, New Zealand (G. J. Williams, *Quart. Jour. Geol. Soc.*, 90, 1934, 323).
4. Aplite, Felka Valley, Tatra Mts., Czechoslovakia (E. v. Lengyel, *Neues Jahr. f. Min. etc., Ref. II*, 1935, 408).
5. Aplite, valley of W. Webburn, Dartmoor (A. Brammall and H. F. Harwood, *Quart. Jour. Geol. Soc.*, 87, 1932, 171).
6. Aplite, Black range, Rochester district, Nevada (A. Knopf, *U.S. Geol. Surv. Bull.*, 762, 1924, 33).
7. Soda-aplite, Port Elliot, Encounter Bay, S. Australia (W. R. Browne, *Trans. Roy. Soc. S. Australia*, 44, 1920, 29, anal. 1).
8. Diabase-aplite, Palisade Sill, New Jersey (F. Walker, *Bull. Geol. Soc. America*, 51, 1940, 1059).
9. Albite-aplite, contact zone of Merawan batholith, Java (R. van Bemmelen, *De Ingenieur in Nederlandsch-Indië*, iv, 4, no. 1, 1938, 9).
10. Soda-aplite, vein in diabase, James Township, Gowganda Lake district, Ontario (N. L. Bowen, *Jour. Geol.*, 18, 1910, 667).

is albite. Two chief modes of origin for such rocks may be suggested : (*a*) the albite may have crystallized out from the magma as a primary mineral, (*b*) the albite may be secondary and have been formed through the albitization of an ordinary granite-aplite or similar rock. It should be possible to distinguish between these modes of origin in favourable cases because, in the first, the proportions of albite and quartz will approximate more or less closely to those of the eutectic between these two minerals, whereas in the second there need be no such approximation. Moreover, as the eutectic composition is about albite 67 per cent, quartz 33 per cent, the albite-aplites formed by the albitization of normal granite-aplites will, in general, be richer in quartz, unless we also suppose this mineral to have been replaced by albite to some extent.

That these two varieties of albite-aplite do occur in nature appears to be indicated by the data given in Table II (cols. 7 to 10). The first two aplites (nos. 7 and 8) show a very close approach to the composition of the albite-quartz eutectic and may well represent residual magmas. The other two (Nos. 9 and 10) are too rich in

TABLE III

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
qz .	39	36	32	30	30	28	28	26	26	26	25	25	23	21
or .	3	5	46	59	51	54	54	55	55	56	53	53	56	60
ab .	45	48	21	10	18	18	18	17	17	17	20	20	20	18
an .	13	11	1	1	1	—	—	2	2	1	2	2	1	1

NOTES TO TABLE III

1. Oligoclase graphic granite, Ytterby, Sweden (A. Bygdén, *Bull. Geol. Inst., Upsala*, 7, 1906, 8).
2. Oligoclase graphic granite, Asjörnsodde, Norway (J. H. L. Vogt, *Skrift. Det Norske Videnskaps-Akad, Oslo, I. Mat-nat. Kl.*, 1930, no. 3, 117).
3. Graphic granite, Mursinka, Ural Mts. (N. Sundius, *Sver. Geol. Undersök*, Ser. C., 336, 1926, 33).
4. Graphic granite, Skarpö, Sweden (A. Bygdén, *Bull. Geol. Inst., Upsala*, 7, 1906, 5).
5. Graphic granite, Svinö, Åland (N. Sundius, *Sver. Geol. Undersök*, Ser. C., 336, 1926, 33).
6. Graphic granite (coarse), Fisher's quarry, Topsham, Maine (E. S. Bastin, *U.S.G.S., Bull.* 445, 1911, 124).
7. Graphic granite (moderately coarse), Fisher's quarry, Topsham, Maine (E. S. Bastin, *U.S.G.S., Bull.* 445, 1911, 124).
8. Graphic granite, Arendal, Norway (J. H. L. Vogt, *Vidensk-Selsk. Skrift. I. Mat-nat. Kl.*, Christiania, 1904, no. 1, 120).
9. Graphic granite, Anita mine, Riverside County, California (R. C. Wells, *U.S.G.S., Bull.* 878, 1937, 13).
10. Graphic granite, Evje, Norway (J. H. L. Vogt, *Skrift. Det Norske Videnskaps-Akad., Oslo, I. Mat-nat. Kl.*, 1930, no. 3, 116).
11. Graphic granite, Hitterö, Norway (J. H. L. Vogt, *Vidensk-Selsk. Skrift. I. Mat-nat. Kl.*, Christiania, 1904, no. 1, 120).
12. Graphic granite, same locality and reference.
13. Graphic granite (fine grained), Kinkle's quarry, Bedford, New York (E. S. Bastin, *U.S.G.S., Bull.* 445, 1911, 124).
14. Graphic granite, Elfkarleö, Sweden (A. Bygdén, *Bull. Geol. Inst. Upsala*, 7, 1906, 4).

quartz and must have been produced by the albitization of ordinary granite-aplites or possibly by deposition from solutions as suggested by Bowen (1910, 669) and Van Bemmelen (1938, 10).

Before closing a word should perhaps be said on the subject of the graphic intergrowths between quartz and felspar found in many granite-pegmatites. Most petrologists are agreed that these intergrowths represent a simultaneous crystallization of the two constituents. In the case of the plagioclase-quartz intergrowths reference to Table III (cols. 1 and 2) and to Text-fig. 4 is sufficient to show that they must lie practically on the plagioclase-quartz boundary surface and presumably the whole of their crystallization would take place on this surface with the simultaneous separation of plagioclase and quartz. But in the case of the potash felspar-quartz intergrowths, the bulk

composition lies well within the potash felspar field and close to the Or–Ab–Qz face of the tetrahedron (Table III, cols. 3 to 14, and Text-fig. 4). Here, therefore, potash felspar alone would begin crystallizing out and would be joined by quartz only after the liquid had reached the potash felspar-quartz boundary surface, when the two minerals would continue to crystallize out together. It should, however, be emphasized in this connection that dry melt diagrams may not be applicable when discussing the phase relationships of granite-pegmatites.

I wish to thank Mr. K. Rickson, of the Department of Mineralogy and Petrology, Cambridge, for drawing the diagrams which illustrate this paper.

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The Significance of Variation in Granites

By R. H. Rastall

THE object of the present short paper is to draw attention to what seems to the writer to be a rather important omission in most recent discussions of the origin and nature of granite. In these discussions the word granite or almost equally often the word granodiorite are used as if it was to be assumed that all granites are alike and all granodiorites alike. In what follows, for the sake of brevity, all will be called granites, as a general class-name, without discriminating each time on small points of petrographical difference. Now all granites are not alike, by any means. They show wide variations, not so much in their main components of quartz, felspar, and ferromagnesian minerals (the essential minerals, according to definition), but in their minor constituents and accessory minerals and still more in some of their accompanying phenomena. By this last expression is intended not so much their metamorphic effects, in the narrow sense of the word, but what is commonly called pneumatolysis, and still more importantly, the accompanying ore-deposits, if indeed it is possible to discriminate between these two categories.

In all modern discussions of the formation of granite, to use a completely non-committal word for its origin, a most important question arises, and there is usually little or no attempt to supply an answer. That is the question whether there is any real difference between the emanations which now play so important a part in all discussions, and the agents which bring about what has long been known as pneumatolysis. From one point of view it is possible to regard all the processes involved in what is now called granitization as pneumatolysis, since they are supposed to be brought about by the action of fluids, whether liquids or gases. Whether they are actually to be regarded as liquids or gases is of no importance as under the conditions postulated the fluids would almost certainly be above their critical points, where the distinction vanishes. One important point here is that most of the effects usually called pneumatolysis and especially the formation of ore-deposits certainly take place at a late stage in the formation of the granite, and it is of course obvious that by some means or other many of the rarer constituents of the earth have been concentrated into these late deposits. This is a point obviously needing very special consideration.

It will be well to note very briefly some of the major variations that are found to exist among granites in regard to their essential constituents. The first thing that suggests itself is the distinction commonly drawn between the alkali-granites and the not-so-alkaline granites. Now as a matter of fact this really resolves itself into the

distinction between granite *sensu stricto* and granodiorite. Most of the highly alkaline granites contain muscovite, especially if they are rich in potash, while the granites with dominant biotite and especially hornblende are now commonly called granodiorite. But there is one special class of alkali-granite that needs particular attention ; that is the soda-granite class carrying ferromagnesian minerals rich in soda, such as arfvedsonite, riebeckite, and aegirine. These always show close relationship to syenites and these to nepheline-syenites and other even more basic types, so that the series is actually carried out of the granitization sphere altogether. It cannot be denied that a series of this kind, such as that at Oslo, does favour the theory of magmatic differentiation, and it has to be remembered that some of these alkaline petrographic provinces are on a large scale ; they are not mere local episodes which can be put comfortably into the category of small intrusions, which some writers regard as outside the sphere of granitization. If the granitic member of such a series is to be regarded as formed by alteration of some pre-existing rock, why should not a similar explanation be applied to the accompanying alkali-gabbro ? It seems to the writer that at the present stage of the granite problem this and similar questions have got to be faced. At any rate in the case of the Oslo province it would seem illogical to suppose that the granite and perhaps the still bigger nordmarkite were formed by one set of processes and the obviously closely related basic members by a totally different set of processes.

It would no doubt be possible to go on multiplying instances of this sort of thing almost indefinitely, even in the case of the alkaline rocks, while among the calc-alkaline igneous complexes there are many examples of sequences of a similar kind, from acid to basic or even ultrabasic, where the same difficulty arises.

But it will be more profitable to go on to consider the wide range of variation that is shown in the latest phases of granite formation, both on account of its importance in the general theory, and even more so because of its economic bearings, which relate to practically the whole field of mining of the non-ferrous metals, except the platinum group and one or two others which belong rather to the ultrabasic rocks and therefore mainly to the basalt magma. It may be noted here, as a minor digression, that the study of ore-deposits lends no support whatever to the theory of differentiation of granite magma from basalt, but rather the reverse. It is impossible to believe that all known basalts could have been cleared so completely by differentiation of whole groups of elements that characterize ore-deposits related to granites ; to quote only two examples, tin and tungsten.

It is hardly necessary at this time of day to point out the close connection that exists in innumerable mining districts between masses

of granite and ore-deposits, or to give a list of the metals there found. However, it may just be said that in few parts of the world is the connection so close and so obvious as in Cornwall, where indeed the close relation of ore-deposition to conditions of temperature and pressure is specially clear, in the form of zones around the granite cupolas, with the ores clearly arranged on a descending temperature gradient.

Now Cornwall affords the finest example known of the tin-tourmaline facies. In the Malay States, the world's biggest tin-producer, there is plenty of tourmaline, and I believe it is a fact that wherever tin occurs there also is tourmaline; although the reverse is not true. Still tourmaline forms a good indicator of where to prospect for tin. The Cornish facies also extends widely into Brittany, the Erzgebirge, Spain, and Portugal and in every case is associated with Hercynian granites, whereas the Caledonian granites of Europe contain no tin. The Malayan tin-bearing granites are of late Mesozoic date, probably Cretaceous. It would take up too much space to enumerate the conditions in the other tin-producing regions of the world, but the point to be made here is that this particular facies is peculiarly local and does not occur in other granites of different date in the same areas, as in Europe. Curiously enough the Caledonian granites of Britain are particularly poor in ore-deposits. It is generally believed that the particular association of tin and tungsten with tourmaline is based on the presence of fluorine and boron in the volatile phase of the later stages of cooling.

Now all this detail leads up directly to a rhetorical question: why is this facies so narrowly localized both in time and space? How and why does it happen that the Caledonian and Hercynian granites of the British Isles differ so widely in their accessories and final concentrates, whereas there is really not a very great difference in the essential minerals of the Cornish granites and of the more acid granites of the Lake District and Scotland.

A brief consideration may now be given to another type of ore-deposit very commonly associated with granite. It is well known to everybody that there is no gold-mining in the British Isles. The ancient inhabitants of Ireland apparently got hold of a considerable amount of gold somewhere, and the Romans probably mined gold in Caermarthenshire; a very little has been found in tin-washing in Cornwall and some gold was worked not very long ago in Merionethshire, but that is all. Now in very many other parts of the world gold is common in association with granitic rocks, conspicuously so in America; many of these are more particularly in association with the less acid types; granodiorite, tonalite, and what in America is often called monzonite, which is much the same as tonalite. Moreover, the occurrence of

gold in quartz-veins, which are often direct continuations of pegmatites, is very common. Here again, as likewise in the innumerable places where non-ferrous metals, copper, lead, zinc, and so on occur in or near granites, there are endless examples of specialization of the kind already mentioned. Here it is to be noted that this kind of specialization is to be observed in absences of particular metals and gangue minerals, just as much as in their presence. This applies to such minerals as fluorite and barytes, and is as significant as the presence of concentrates of metals.

It should be emphasized that ore-deposits, even of the lowest possible grades, are always very definitely concentrates, since all the useful metals except iron, aluminium, and magnesium are included in the one-half of one per cent or thereabouts of the minor elements in Clarke's well-known table of the composition of the earth's crust so far as it is accessible, while the individual percentages are very low figures indeed. If these minute quantities were ever distributed anything like evenly throughout the silicate crust, some very efficient processes of concentration must have been at work, both in respect of the very definite association of particular metals with particular rock-types and the local distribution of the same. These special processes of concentration must have some relation to the general question of the origin of the rock-types which they accompany and need to be taken into consideration in any general discussion of the origin of such rocks. It can hardly be denied that most of the phenomena here briefly discussed are most easily explicable by some theory of magmatic differentiation, and are therefore worthy of serious consideration by proponents of other ideas.

Hercynian Fe-Mg Metasomatism in Cornwall: A Reinterpretation

By DORIS L. REYNOLDS

IN connection with a recent investigation of the geochemical changes leading up to granitization, the writer (Reynolds, 1946) had occasion to plot the chemical analyses of the rocks of the Kenidjack and Botallack region, Cornwall (Tilley and Flett, 1930 ; Tilley, 1935) on a von Wolff diagram. Since the diagram required somewhat lengthy discussion, however, it was not included in the geochemical paper. The diagram is nevertheless of interest because it presents in a new form the problem of the genetic associations of these curious rocks, characterized as they are by anthophyllite, cummingtonite, cordierite, and grunerite, and provides useful hints which might form a basis for further field investigations in Cornwall. The present paper, offering tentative interpretations of some of the Cornish rocks, is written in the hope of focusing attention on the petrogenetic significance of this region, and thus of stimulating detailed investigations, with strict correlation between field observations and chemical analyses, by which means alone the problems presented can be solved.

In 1930 Tilley and Flett described, and discussed the origin of, the anthophyllite-cordierite rocks, associated with cummingtonite-bearing varieties, from the Kenidjack area, Land's End. These rocks, occurring in an area that has been subjected to intense shearing, are abnormally rich in iron and magnesia as compared either with basic igneous rocks or with normal sediments. It is thus clear that whatever their origin may have been they are now so highly altered that it is by no means obvious whether they represent sedimentary or igneous rocks. Tilley and Flett considered both these possibilities. They suggested that if the rocks represent altered sediments then their abnormal composition might depend on either of two possibilities ; they may represent either (1) sediments which were abnormally rich in chloritic material, or (2) sediments that have been metasomatically altered by introduction of magnesium and iron. The former of these suggestions they discarded on account of the absence of similar mineral assemblages amongst the bands of hornfelsed sediments adjoining the granite, and on account of their intimate association with " greenstones ". In considering the second possibility as to a sedimentary origin, they drew attention to the somewhat similar rocks described by Eskola (1914) from the Orijärvi area. In the Orijärvi area anthophyllite-cordierite rocks have been developed from leptites, and cummingtonite-plagioclase rocks from amphibolites, as a result of large scale introductions of magnesium and iron. Eskola regards the alteration as being of pneumatolytic

type, and related to the emplacement of the adjoining oligoclase-granite. Tilley and Flett ruled out such an origin for the Cornish rocks, however, for two very good reasons : (*a*) the absence of such alteration in the normal hornfelses occurring in immediate contact with the Land's End granite, and (*b*) the inherent difficulty in believing that magnesia-rich solutions could be available in the residual liquids of granitic magma.

In favour of the alternative view that the anthophyllite-cummingtonite-cordierite rocks represent basic igneous rocks, Tilley and Flett stressed the fact that they are associated with " greenstones ", within which they occur as bands and lenses, and to which they grade. The " greenstones " they regarded as being altered doleritic intrusions.

It was finally concluded in the 1930 paper that the present day association of anthophyllite-cummingtonite-cordierite rocks with " greenstones " is to be attributed to an initial extreme weathering of doleritic rocks, from portions of which lime and soda were thereby leached. Subsequent intense shearing, followed by contact metamorphism, were then believed to have resulted in the development of anthophyllite-cummingtonite-cordierite rocks from the weathered portions, whilst the " greenstones " were developed from the relatively lime-rich parts.

In 1935 Tilley provided additional mineralogical details of the rocks concerned, together with six new chemical analyses, including two of the " greenstones ". Moreover, he recorded the presence of cordierite-biotite-hornfelses and grunerite-biotite-hornfelses, types not previously recognized in the area, which he regarded as still more extreme variants from the initial " greenstones " than are the anthophyllite-cummingtonite-bearing varieties previously discussed. In reconsidering the question of the origin of the rocks, Tilley now showed that the idea previously favoured by Tilley and Flett was untenable, since the present day products of weathering of basic igneous rocks are not chemically similar to the Cornish rocks. Metasomatic alteration of pre-existing rocks thus remained as the only possible explanation of the anthophyllite-cummingtonite-cordierite rocks, and Tilley concluded that these Fe-Mg rich rocks were developed from basic igneous rocks, now represented by the " greenstones " of the area, by a process involving a widespread removal of lime, and an addition of silica and alkalis, particularly potash. He believed there had been internal migration of magnesia, as contrasted with accession of magnesia from an external source such as characterizes the Orijärvi and Falun regions.

With the advance of knowledge since 1935 other possibilities as to the origin of the anthophyllite-cummingtonite-cordierite rocks have become apparent. Fe-Mg metasomatism is now a well-known process, and there is no longer any need to discard the idea because of the

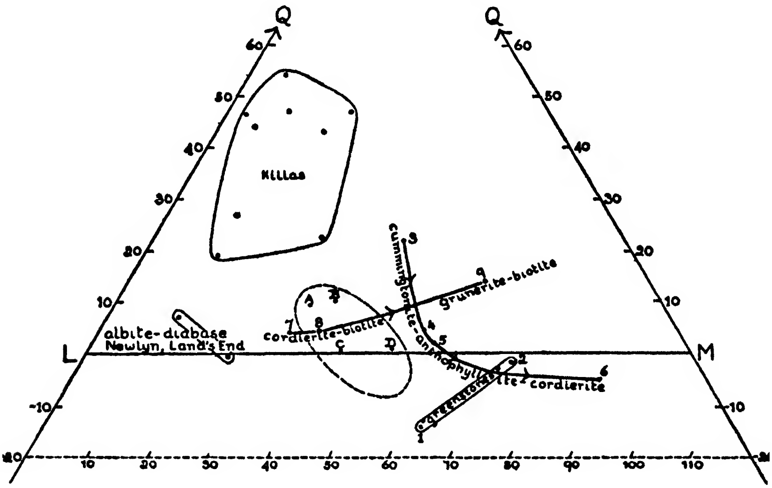
" difficulty in believing such magnesia-rich solutions are available in the residual liquids of granitic magma " (Tilley and Flett, 1930, p. 37). Fe and Mg are now known to become displaced from rocks, both igneous and sedimentary, undergoing granitization, and to become fixed in a frontal zone in advance of the main theatre of granitization ; granite magma is not their source. Nor does the absence of such Fe-Mg metasomatism from the sediments in immediate contact with the Land's End granite any longer rule out the possibility of such a process having been active in Cornwall. It rather becomes necessary to consider whether there has been an Fe-Mg metasomatism of a regional type, as in the Pre-Cambrian of Scandinavia, which antedated the emplacement of the granite. Moreover, once it is realized that the Cornish anthophyllite-cummingtonite-cordierite rocks may be a product of Fe-Mg metasomatism, it becomes necessary to re-examine the possibility as to whether these rocks may have had a sedimentary origin. Indeed, from the triangular diagram, Fig. 8, illustrating Tilley's 1935 paper, it is evident that the rocks in question lie in a region between the field for slates and the corner of the diagram representing FeO + MgO, so that there is a distinct possibility that they may represent original sediments metasomatically enriched in Fe and Mg. The possibility of a sedimentary origin, however, was discarded by Tilley and Flett not only because of the difficulty of believing in an Fe-Mg metasomatism, but also because of the constant association of the anthophyllite-cummingtonite rocks with " greenstones " of supposed igneous origin. A further question therefore arises concerning the evidence that the " greenstones ", now metamorphic rocks, were originally igneous.

The von Wolff diagram, Text-fig. 1, gives a pictorial view of the chemical relationships of the rocks under discussion, and presents the problem in a new light. It is clear from this diagram, for example, that the rocks form not one series, as Tilley appears to have supposed, but two quite distinct series. One series shows variation from cummingtonite-plagioclase-hornfels (3) through cummingtonite-anthophyllite-cordierite-plagioclase-hornfels (4), and anthophyllite-cordierite-hornfels (5), to anthophyllite-cordierite-spinel-diaspore-hornfels (6) ; whilst the other shows variation from cordierite-biotite-hornfels (7 and 8) to grunerite-biotite-hornfels (9). It is equally clear from the diagram that the analysed " greenstones " (1 and 2) do not chemically constitute end members of either of these series, a fact which casts doubt on the suggestion that the " greenstones " represent the parent rock from which the other varieties were developed.

It will be convenient to consider first the origin of the " greenstones ", and subsequently the origin of the two rock series depicted on the von Wolff diagram. It should be stressed at the outset, however,

that the diagram merely indicates chemical relationships, and cannot in itself be used to solve the problem of the origin of the rocks, the solution of which must rest in a correlation of field, mineralogical, and chemical evidence.

What, then, are the analysed " greenstones "? They consist essentially of hornblende, bytownite (β = 1·569), ilmenite and sphene, but they may, in addition, contain granules of colourless augite. Tilley (1935) records the fact that there is considerable variation in the relative



TEXT-FIG. 1.—von Wolff diagram of the rocks of the Kenidjack and Botallack area. L = felspars, M = saturated melanocrats, and Q = quartz. The numbers refer to the chemical analyses of the rocks recorded by Tilley (1935, p. 182). The field for normal basalts and dolerites, indicated by the dashed line enclosing A, B, C, and D, is shown for comparison with the " greenstones ". A = Kennedy's (1933) olivine-basalt " magma-type " for the British Tertiary province ; B = Kennedy's tholeiitic " magma-type " for the British Tertiary province ; C = Daly's average for all basalts ; and D = Daly's average for plateau basalts.

proportions of the component minerals, and that banded types are common. Thus some of the rocks are dominantly hornblendic, hornblende forming more than 80 per cent of the rock, whilst others exhibit alternate bands of hornblende and bytownite. The " greenstones " are, indeed, amphibolites ; mineralogically they might be regarded as hornblende-eucrites.

In 1909, as a result of an extensive and careful field and microscopic investigation of the Laurentian amphibolites of Canada, Adams demonstrated that these rocks have originated in two contrasted ways : (1) by alteration of basic dykes and similar igneous intrusions, and (2) by the metasomatic alteration of limestone. Since the time

of Adams's investigation, amphibolites and " greenstones " of both types of origin have been recorded from many areas. Yet from a study of the records of such investigations it is evident that without field criteria it may be no easy matter to discriminate between amphibolites of igneous and limestone origin since, both mineralogically and chemically, the two varieties appear to show convergence. In the case of the hornblende-bytownite-" greenstones " under discussion, however, all the recorded evidence is in favour of a limestone rather than of an igneous origin. A strong point of evidence in favour of a limestone origin is the fact that the hornblende-bytownite-" greenstones " are associated with a rarer type of hornfels containing the lime-rich minerals grossular, epidote, diopside, and axinite. Not only does this association remain unexplained if the " greenstones " are regarded as representing basic igneous rocks, but so also does the high lime content of the " greenstones " themselves. Of the two analysed " greenstones " (Tilley, 1935, p. 182) one contains 14·00 and the other 14·82 per cent of lime, whereas normal basalts and dolerites rarely contain more than 11. In explanation of this anomaly Tilley remarks that " it seems probable that these greenstones may have suffered some enrichment in lime during the shearing . . . to which they have been subjected " (Tilley, 1935, p. 184). This is no adequate explanation of the high lime content, however, since such chemical evidence as has been recorded indicates that lime decreases when rocks are subjected to shear (Cooke, 1927). Other chemical peculiarities of the two analysed " greenstones ", that are more compatible with a limestone origin, are their low percentages of silica and soda. Comparison of the position of the two analysed " greenstones " on the von Wolff diagram, Text-fig. 1, with the field of normal basalts and dolerites shows that the " greenstones " are richer in melanocratic constituents than normal basaltic rocks, and that one of the " greenstones " is chemically highly undersaturated as compared with basaltic rocks. If the " greenstones " are metamorphosed basaltic rocks they must still, therefore, be considered to have undergone metasomatic alteration.

A further striking fact at variance with the supposed igneous origin of the " greenstones " is that there are recognizable igneous greenstones in Cornwall, and that these, as would be expected in such a geological setting, are of spilitic type, characterized in contrast with the " greenstones " under discussion, by richness in soda and poorness in lime, and by oligoclase or albite-oligoclase as distinct from the bytownite of the Kenidjack " greenstones ". A further mineralogical point of discrimination is the presence of colourless monoclinic pyroxene in the hornblende-bytownite-" greenstones ", as contrasted with the constant purplish colour of the augite in the greenstones of

spilitic origin. Tilley (1935, p. 185) records a greenstone from the south-west side of Kenidjack cliff that is obviously of igneous origin since it exhibits pillow structure, but this rock, judging from his description, is of spilitic type, and stands in contrast with the hornblende-bytownite-" greenstones ".

The balance of the recorded evidence is in favour of a limestone rather than of a basaltic origin for the hornblende-bytownite-" greenstones " of the Kenidjack area ; indeed, the association of these rocks with hornfelses characterized by grossular, epidote, and diopside might perhaps even be regarded as proof of such an origin. However this may be, it is evident that whether the " greenstones " in question were originally limestones or basaltic rocks they have, in either case, suffered extensive metasomatic changes. If they were originally limestones they have been enriched in Al, Fe, Mg, and to a smaller extent in alkalies, with concomitant loss of Ca and CO_2 ; whereas, if they were originally basalts or dolerites, they have gained cafemic constituents, principally Ca, and lost Si and alkalis.

Turning next to the cummingtonite-anthophyllite series represented by points 3, 4, 5, and 6 on the von Wolff diagram, Fig. 1, the diagram shows not only that the hornblende-bytownite-" greenstones " do not constitute a chemical starting point for this series, but also that the series does not spring from a chemical field of normal igneous rocks. Chemically the series is characterized by falling SiO_2 and CaO, together with increasing Al_2O_3, FeO, MgO, alkalis, TiO_2, and MnO. It can, therefore, be fairly deduced that the parent rock contained more than 58 per cent of SiO_2, and more than 5·42 per cent of CaO, the quantities shown by the initial term (3) of the series. From a study of the chemistry of the series, and from knowledge of the chemical changes undergone by rocks during the preliminary change of desilication and basification which precedes granitization (D. L. Reynolds, 1946), one might hazard the suggestion that this series represents the desilication and basification of a calcareous shale. Mineralogical evidence consistent with this suggestion is the more common occurrence of quartz in the cummingtonite-bearing hornfelses that form the initial terms of the series, than in the anthophyllite-bearing end members ; the common occurrence of plagioclase (labradorite to andesine) in these initial types ; and the presence of zircon. Decisive proof relating to the origin can only be found, however, by a careful search for parental relics amongst the cummingtonite-anthophyllite rocks both in the field and in microscope section.

It is clear from the von Wolff diagram, Text-fig. 1, that the cordierite-biotite → grunerite-biotite series (7 to 9) forms a chemically distinct suite, and not an end stage of the alteration of the cummingtonite-anthophyllite varieties. It stands in contrast with the latter series,

moreover, in that it is characterized by decreasing MgO, alkalis, and Al_2O_3. By continuing the chemical variation of the series back beyond the initial term (7), it is apparent from the chemical analyses of the rocks that the parent rock must have been characterized by about 50 per cent SiO_2, and have contained more than 7 per cent of alkalis, and more than 5 per cent of MgO. These criteria appear to be more suggestive of a basic igneous rock, rich in alkalis, than of a sedimentary rock as the parent type. The cordierite-biotite-hornfelses consist essentially of cordierite, biotite, albite-oligoclase, and quartz, and are thus mineralogically related to the pillow lavas exposed on the south-western side of Kenidjack cliff (Tilley, 1935, p. 185, and plate vii, fig. 4). These pillow lavas are composed essentially of biotite and oligoclase, with some quartz, muscovite, and chlorite. Such a biotite-oligoclase rock would form a natural starting point from which the cordierite-biotite-hornfelses could be developed, since the cordierite is known to replace plagioclase (Tilley, 1935, p. 188) ; such a change would involve addition of Fe. Again, however, complete proof as to the origin of these rocks can only be found in the area itself.

There is then a certain amount of suggestive chemical and mineralogical evidence that the hornblende-bytownite-" greenstones ", anthophyllite-cummingtonite-hornfelses, and cordierite-biotite-hornfelses of the Kenidjack area were developed from a sedimentary series, including limestones and calcareous shales, with intercalations of igneous rocks of spilitic type. If such is the case, then the change of all the rock types becomes unified and explicable as the result of an Fe-Mg metasomatism comparable with that known in Scandinavia. If, on the other hand, the hornblende-bytownite-" greenstone " is regarded as a parental igneous rock from which the other varieties were derived by metasomatism, as Tilley supposes, then the processes of change lack unity, and vary from one rock to another. The blurred gradational contacts between the various rock types, previously regarded as proof that one variety has been derived from another, are readily explained as a result of internal migrations, whilst the occurrence of anthophyllite-cummingtonite rocks as lenses within the " greenstones " may well be a relict boudinage structure. Flett has, indeed, described actual " crush conglomerates " composed of killas and greenstone from the cliffs at Botallack itself (Flett, 1907, p. 27).

Continuing this line of argument, in spite of the lack of complete proof as to the origin of the rocks under discussion, questions next arise as to a possible source for the Fe and Mg necessary for such a metasomatism, and as to the time at which it took place. Tilley and Flett have already shown that any metasomatic alterations the original rock suite may have undergone can hardly be attributed to the Land's End granite, because bands of sediment in immediate

contact with the granite show no such alteration. Further, the alterations clearly antedate the pneumatolytic changes attributable to the granite, for the anthophyllite-cordierite rocks are sometimes tourmalinized, tourmaline having formed largely at the expense of cordierite (Tilley and Flett, 1930, p. 32). Is there not here perhaps some hint that the metasomatic changes under discussion were of a regional type ? The answer must obviously lie in an examination of the evidence presented by the Cornish rocks as a whole.

The " greenstones " of Cornwall have been a subject of interest since 1793 when Hawkins sent a collection of specimens of Cornish rocks to Werner for identification. Werner classified the rocks as clay-slate (killas) and hornblende-slate. In 1820 Sedgwick distinguished two varieties amongst the hornblendic rocks, viz. greenstone and hornblende-rock. Forty years later David Forbes, after examining the greenstones depicted on the Geological Survey maps of Cornwall, came to the conclusion that the term " greenstone ", with its implication of an igneous origin, was a misnomer, and that the greenstones he examined were metamorphosed clay-slates. In later years Phillips undertook a detailed investigation of the Cornish rocks in order to settle the vexed question as to the igneous *versus* sedimentary origin of the so-called " greenstones ". In a series of papers published in 1875, 1876, and 1878 he recorded the results of his researches on the field occurrences, microscopic characters, and chemistry of the Cornish rocks, presenting forty chemical analyses of the " greenstones " and killas. As a result of his investigations Phillips came to the conclusion that the rocks under consideration could be divided into three distinct classes : (1) intrusive and extrusive basic igneous rocks and basic tuffs, (2) killas, or ordinary clay-slates, and (3) highly basic hornblendic rocks with a tendency to break in parallel planes, and having the appearance, under the microscope, of metamorphic slates.

On chemical and mineralogical grounds Phillips thus distinguished two varieties of " greenstones ". The igneous variety he recognized not only from the massive appearance of the rocks in the field, but also from the fact that the original minerals are still recognizable in thin section. Chemically they are of spilitic type, as shown by a representative series of Phillips's analyses reproduced in the adjoining Table (Nos. 1–5).

The hornblendic rocks of sedimentary origin were found by Phillips to differ chemically from the igneous varieties, and to show a surprising chemical uniformity amongst themselves. He pointed out that they contain, on average, 10 per cent less SiO_2 than the basic igneous rocks, and correspondingly higher iron oxides. A representative series of Phillips's chemical analyses of these rocks is set out in the Table. As Phillips himself points out, the two varieties of " greenstone "

CHEMICAL ANALYSES OF CORNISH "GREENSTONES", BY J. A. PHILLIPS

	1	2	3	4	5	A	B	C
SiO_2	46·32	46·40	50·42	43·23	40·05	37·44	39·20	35·58
Al_2O_3	18·18	20·33	19·01	21·37	20·46	16·32	16·22	21·14
Fe_2O_3	·82	4·44	2·47	1·69	1·83	7·33	4·82	14·74
FeO	10·92	5·96	11·07	9·53	12·66	14·75	15·88	10·32
MgO	7·46	3·85	1·76	3·57	4·28	6·06	6·56	2·78
CaO	9·32	6·04	5·86	6·66	6·62	12·83	10·70	9·20
Na_2O	2·95	5·05	5·18	5·63	4·82	1·85	1·45	2·11
K_2O	2·07	1·89	1·64	trace	trace	1·50	2·69	·95
H_2O +	·76	2·01	·69	3·98	4·30	·77	·87	1·56
H_2O −	·24	·31	·29	·51	·56	·54	·53	1·37
CO_2	—	2·32	—	2·61	3·67	—	—	—
P_2O_5	·52	·92	·79	·97	·63	·27	·74	trace
MnO	trace	trace	·41	trace	trace	trace	—	trace
Li_2O	—	trace	·12	—	—	—	—	—
FeS_2	·32	—	·43	·33	trace	·23	—	trace
	99·88	99·52	100·14	100·08	99·88	99·89	99·66	99·75
S.G.	3·02	2·98	2·97	2·82	2·83	3·29	3·26	3·15

1. Albite-dolerite, partly amphibolitized, amphibole mainly replacing the albite. Tolcarn, 1876, p. 162.
2. Albite-dolerite. Wearde, 1878. Average of duplicate analyses on p. 492.
3. Albite-dolerite, partly amphibolitized, amphibole mainly replacing the augite, and partly replacing the albite. Sanctuares, 1878. Average of duplicate analyses on p. 472.
4. Amygdaloidal spilite, Pentire Point. 1878, p. 482.
5. Amygdaloidal spilite. Port Isaac. 1878, p. 482.

A. Amphibolite, Paul Hill. 1876, p. 165, no. I.
B. Amphibolite, Chyandour, Penzance. 1876, p. 165, no. III.
C. Amphibolite. Rosehill, Castle Horneck. 1876, p. 165, no. II.

are chemically distinct, and no chemically intermediate types were discovered.

Thirty-two of Phillips's thin sections of the Cornish rocks are now in the possession of the Geological Survey, and the writer gratefully acknowledges the privilege of having been allowed to examine them. Fifteen of the sections represent analysed rocks, and amongst them five represent the variety of "greenstone" classed by Phillips as of sedimentary origin. Of the remaining rock sections, a few are of pelitic types, but the majority are spilitic rocks in various stages of alteration.

The rocks of spilitic type include both intrusive and extrusive varieties, viz. albite-dolerites, epidiorites, and spilites. All are easily recognizable as of igneous origin. The albite-dolerites are characterized by albite or albite-oligoclase, purplish augite, titaniferous iron ore and abundant needles of apatite. Brown hornblende is sometimes present. Alteration of these rocks appears first around the margins of the augite crystals, where a bluish green amphibole of hastingsite type develops. Three sections of these albite-dolerites represent advanced stages of alteration. In two of these augite is almost

completely replaced by a hastingsitic amphibole, only small relics of purplish augite remaining as cores within the amphibole. In the third section the augite is completely replaced by fan-like groups of hastingsitic amphibole, which appear along the margins of the albite crystals. In all three of these rocks, however, the plagioclase is clearly recognizable, so that there is no doubt as to the identity of the rock types. Both the spilites and the epidiorites are of normal appearance, the epidiorites being characterized by a bluish-green amphibole.

The " greenstones " classed by Phillips as of sedimentary origin are seen from the thin sections to be amphibolites. Two of the sections of amphibolite, from rocks outcropping at Paul Hill and Chyandour, represent analysed rocks, and a third section of amphibolite, from Tingey quarry, shows the rock to be of a similar type. These rocks consist almost entirely of sheaf-like bluish-green amphibole, together with some epidote, iron ore and, more rarely, biotite. The amphibole has $Z_{\wedge}c = ca\ 21°$; Z = greenish-blue, Y = olive green, and X = straw colour; 2V, judged from β sections, is about 80°. The marked blue colour of the amphibole suggests that it is a variety of hastingsite, and this is confirmed by the chemical analyses of the rocks concerned (see Table of chemical analyses, p. 41, A, B and C). The absence of chemically and mineralogically intermediate types between the igneous varieties of greenstone and the highly basic amphibolites may be regarded as proof that the latter were not derived from the former. In the light of Adams's (1909) work one is tempted to believe that these highly basic amphibolites represent altered limestones, but once again this supposition can only be adequately tested by further field investigation. It is, however, quite clear that they cannot be matched by either igneous or normal sedimentary types, so that it can be concluded that they have undergone radical chemical change, and that, whatever their origin may be, they have been markedly enriched at least in Fe.

A section of amphibolite from a mile south-east of Callington, in Eastern Cornwall, is of interest since it is composed of several varieties of amphibole together with chlorite. In this rock large crystalloblasts of tremolite are embedded in a felt of radial needles of amphibole, including a hastingsitic variety and an almost colourless variety, possibly anthophyllite. This rock, which is allied to the anthophyllite-cummingtonite-bearing rocks of South-Western Cornwall, has not been analysed, but it must obviously be rich in either iron or magnesia or both. Whether it be an altered limestone or an altered igneous rock it must have suffered great chemical change, involving introduction of one or both of these constituents.

In connection with the suggestion that the highly basic amphibolites may represent altered limestones, it should be noticed that both

limestones and calc-silicate-hornfelses are present in Cornwall; for example, Coles Phillips (1928) has recorded the presence of calc-silicate-hornfelses in Northern Cornwall. A section of one of these rocks, from Camelford, amongst the Survey collection of J. A. Phillips's slides shows it to be a plagioclase-diopside-epidote rock. There is thus a distinct possibility that a detailed search amongst correlatable horizons might reveal a sequence from limestone, through calc-silicate-hornfels to the amphibolites in question.

The chemical analyses of the killas (clay-slate) recorded by Phillips show this formation to be, at least in part, of highly abnormal composition as compared with average pelitic sediments. Not only is the killas sometimes richer in soda than potash, soda in two analysed examples constituting more than 4 per cent of the rock, but iron oxides are also abnormally high in many of the analysed rocks; the total iron oxides recorded reached 18 and 21 per cent.

From this review of the rocks of Cornwall it appears that killas and amphibolites alike represent rocks which have been enriched at least in Fe, and that this enrichment has a widespread distribution. In view of these findings the most satisfactory interpretation of the cummingtonite-anthophyllite-cordierite rocks of the Kenidjack area is that they also resulted from this general introduction of Fe. The additional enrichment of the cummingtonite-anthophyllite rock series (3, 4, 5, and 6) in Mg is probably, as Tilley has suggested, the result of an internal migration of Mg, as contrasted with accession of Mg from an external source. The evolution of the series cordierite-biotite-hornfels → grunerite-biotite-hornfels (7, 8, and 9) involved loss of Mg, and this emigrant Mg may well be the source of the Mg introduced into the adjacent rocks, thus giving rise to the cummingtonite-anthophyllite series. Such an interpretation would account for the blurred contacts between the two series, and the fact that, from field evidence, they have been regarded as one continuous suite. It is, moreover, well established in Scandinavia that country rocks adjoining rocks of basic igneous composition undergo such enrichments as an accompaniment of " granitization ". Such change of composition of clay-slate in contact with a greenstone of igneous origin is, in fact, not lacking in Cornwall. On St. Clere Down, near Liskeard, igneous greenstone is margined by a green slaty rock which passes imperceptibly into the clay-slate (Phillips, 1878, p. 486). From the thin sections of these rocks it is seen that the igneous rock is an epidiorite, and that the green slaty rock is a sedimentary hornfels in which small crystals of brown monoclinic amphibole have developed. Phillips records chemical analyses of both the epidiorite and the amphibole-bearing rock in contact with it (1878, p. 487); as compared with the killas the green slaty rock is strongly desilicated, and probably enriched in Mg.

In a great majority of the chemically investigated occurrences, the emplacement of granite has been accompanied by introduction of Fe and/or Mg into the adjoining aureole of country rocks (D. L. Reynolds, 1946). In considering the source of the introduced Fe in Cornwall it is, therefore, necessary to decide whether such Fe enrichment can be related to the emplacement of the Hercynian granites of Land's End, Falmouth, St. Austell, Bodmin Moor, and Dartmoor. Fe and Mg have certainly been introduced into the aureoles of the granites of Falmouth and Dartmoor, but taken as a whole the degree of such enrichments appears to be small as compared with the Fe enrichment under discussion. On the eastern side of the Dartmoor granite, however, limestone enters the contact aureole, and is converted to andradite-hedenbergite skarn (Fitch, 1932). Such a change involved the fixation of considerable quantities of Fe that must have been migratory at the time of emplacement of the granite. This contrast between the degree of Fe-enrichment of limestone and that of pelitic rocks indicates that differences in the initial compositions of individual country rocks may account for localized concentrations or more widespread dispersal of Fe-enrichment.

Ranged against the possibility that the widespread Fe-enrichment is to be related to the Hercynian granites is the fact that rocks showing such enrichment (e.g. amphibolite, south-east of Callington) sometimes lie well outside the contact aureoles of the granites as delimited by the development of spotted slate.

Another consideration of outstanding importance in any discussion of the source of the Fe is that the mineral facies of the Cornish " greenstones " is very different from that of the andradite-hedenbergite skarn of the Dartmoor area. The Cornish amphibolites, amphibolitized albite-dolerites and epidolerites are all characterized by a bluish-green amphibole of hastingsite type. This bluish-green amphibole is not characteristically developed in zones of contact alteration around granite intrusions; it is commonly, however, the characteristic amphibole in the epidiorites and amphibolites of migmatite areas. Furthermore, the Cornish epidiorites are closely similar to those found within the Dalradians, where the minerals of such rocks are regarded as indicating the grade of regional metamorphism, Wiseman (1934) having shown that the FeO/MgO ratio in the amphibole increases in the higher grades. The FeO/MgO ratios in the Cornish amphibolites are even higher than those recorded by Wiseman. Possibly this may represent a measure of the intensity of the Fe metasomatism to which the Cornish rocks have been subjected.

The weight of evidence is thus against the assumption that the marked Fe-enrichment of many of the Cornish rocks can be correlated with the emplacement of the Hercynian granites. It appears rather

to be a change of composition of regional type antedating the emplacement of the granites, in connection with which emplacement further enrichment in Fe and Mg took place locally.

In order to appreciate the significance of the regional Fe metasomatism in Cornwall, it is necessary to consider the geological setting of this region. The Devonian sediments of Cornwall, with which the " greenstones " are associated, represent a flysch facies (E. M. Lind Hendriks, 1937, 1939) developed along the northern border of the rising Hercynian range. E. M. L. Hendriks has shown, moreover, that these sediments are separated from the highly crystalline rocks of the Lizard, Dodman, and Start peninsulas, to the south, by a thrust. In the eastern part of the Lizard the thrust is associated with a breccia zone in which she has found exotic blocks and fragments of Ordovician quartzites and Upper Silurian limestones allied respectively to the Grès de May and the Orthoceras Limestones of Brittany, and within the breccia zone serpentine is emplaced. She thus demonstrates that the crystalline rocks of the Lizard-Dodman-Start area are the relics of a Hercynian nappe that travelled northwards.

The crystalline rocks of the Lizard and Start peninsulas, which constitute the nappe, were at one time regarded as of Pre-Cambrian age, a conclusion that is now open to doubt. Dr. Hendriks (1939) has drawn attention to the fact that the rock association of the Start peninsula (Tilley, 1923) must originally have been closely similar to the succession in the Gidley Wells beds, of Upper Devonian age, in South Cornwall, whilst Scrivenor (1938, 1939) regards the rocks of the Old Lizard Head series as metamorphosed representatives of an association of killas and basic igneous rocks. There is thus at least a strong possibility that the rocks of the Lizard and Start area represent highly metamorphosed Devonian rocks which were thrust northwards, over less altered varieties, in Hercynian times.

Still further south, in Brittany, there is an association of highly crystalline rocks and sedimentary types ranging up to the Carboniferous in age. Originally the highly crystalline rocks, including granite gneisses, and the overlying sedimentary series—the Brioverian—into which they grade, were all regarded as of Pre-Cambrian age. In 1926, however, Kerforne reported the finding of faunas of Devonian, and probably of Carboniferous age, in part of the Brioverian. Long ago (1900) Barrois stressed the fact that there appears everywhere to be a stratigraphical and lithological passage from the highly crystalline rocks to the Brioverian; a passage " so gradual and insensible that the line of division is purely subjective, and has been drawn at different horizons by different surveyors on the staff of the Geological Survey of France ". Moreover, the rocks known to occur as pebbles within the Brioverian conglomerates do not, according to Barrois, correspond

with the underlying highly crystalline rocks, but are, in fact, identical with the rocks of the Brioverian itself. This latter fact strongly suggests that the rocks older than the Brioverian had not, at the time of deposition of the Brioverian conglomerates, acquired their crystalline dress.

As to the highly crystalline rocks, they include granite-gneisses, with interstratified layers of schist and amphibolite, which pass upward into mica-schist with intercalated pyroxenites, amphibolites, eclogites, and chlorite-schists. The latter, in turn, grade upwards to a series of mica-schists, characterized by the zonal minerals sillimanite, staurolite, and garnet. The uppermost series of schists includes subordinate beds of graphitic quartzite and pyroxene-marble. Of these supposed Archaean rocks Barrois wrote: "It must be confessed that the greater antiquity of the Archaean gneiss, though here admitted, is only a hypothesis. There is every reason for believing that the theory which regards all the gneisses of Brittany as metamorphic products, dating from the beginning of the Brioverian period, makes a nearer approach to the truth." This conclusion of Barrois, in conjunction with the absence of an unconformity in the series, and the findings of Kerforne that the Brioverian is, at least in part, of Palaeozoic age, strongly suggests that the crystalline rocks of Brittany are the products of Hercynian granitization.

This suggestion is strongly corroborated by Demay's (1937) findings. In the Central Massif of France he has recognized the highly crystalline core of the Hercynian belt, and shown it to consist of foliated gneiss, passing outwards through "injection-gneiss" to migmatites, which in turn grade to mica-schist. Within this suite of rocks are amphibolites which Demay (1936) interprets as basic intrusions belonging to the Hercynian orogenic period, but emplaced within the sediments before their granitization. He showed the trend-lines of these products of Hercynian granitization to be continuous with those of Brittany to the north-west, and with those of Bohemia to the north-east (Demay, 1934, fig. 1, p. 343).

The Devonian rocks of Cornwall, with their intercalated "greenstones" were thus developed in the foredeep in front of the rising Hercynian ranges. They represent, in fact, the lowest metamorphic grade of this belt. To the south, in Brittany, the highly granitized core of the belt is exposed. Within this core a suite of sedimentary and igneous rocks, composed of sandstones, shales, and limestones, with intercalated basic igneous rocks, is represented. The original rock varieties are now seen, however, in various stages of "granitization". The shales and sandstones are sometimes represented by schists and migmatitic granite-gneisses. The basic igneous rocks are represented, not by low-grade greenstones as in Cornwall, but by more highly

crystalline amphibolites and eclogites. In the least altered rocks limestones are represented by pyroxene-marble, but within the zones of stronger "granitization" they too are probably represented by amphibolites (cf. Backlund, 1936, 1943, 1946). The interpretation of the rocks of the Lizard, Dodman, and Start peninsulas as Hercynian schists (Scrivenor, 1938, 1939, Hendriks, 1939), of a metamorphic grade intermediate between that shown by the northern marginal rocks and the highly granitized core of the belt, is so consistent as highly to commend its adoption. On this view the Man of War gneiss would be interpreted as Hercynian migmatite.

Backlund (1946) has recently stressed the similarity between the granitized cores of fold ranges of all ages, and it will be clear from the foregoing description what a close correspondence there is between these products of Hercynian granitization and those of the Pre-Cambrian of Fennoscandia (Backlund, 1943).

As already mentioned, in connection with the discussion of the cummingtonite-anthophyllite rocks of Cornwall, cummingtonite-anthophyllite skarn is of common occurrence in Fennoscandia in leptites adjoining both amphibolites and iron ores. All Fennoscandian geologists are now agreed that the cummingtonite-anthophyllite rocks are the result of Mg or Mg-Fe metasomatism, but they differ as to the source of the Mg and Fe. It should perhaps be emphasized at the outset that the cummingtonite-anthophyllite skarns, adjoining intrusive basic igneous rocks, cannot be attributed to any metasomatic effect of the basic magma for in some examples it has been shown that the development of the skarn was posterior to the amphibolitization of the igneous rock (J. A. W. Bugge, 1943). Eskola (1914) has explained the cummingtonite-anthophyllite rocks within the aureole of the Orijärvi granite as a product of pneumatolytic Mg metasomatism, regarding granite magma as the source of the Mg. Sundius (1935) regards the Mg necessary for the development of skarn as a residual magmatic solution derived from granite magma. Magnusson (1940) appeals to solutions circulating through a wide area, in advance of a supposed intruding granite magma, as the source of the Mg. On the other hand, Bugge (1943) stresses the fact that cummingtonite-anthophyllite skarn is commonly developed from leptite at its contacts with amphibolites, such an association indicating a genetic relationship between the skarn and the amphibolite. Bugge regards the Mg necessary for the development of skarn as having been leached from the adjoining amphibolites by advancing solutions in connection with a general migmatization.

The Cornish cummingtonite-anthophyllite rocks, which differ from their Fennoscandian counterparts in being richer in Fe than Mg, should throw considerable light on the question of the origin of these

rock types. At Kenidjack they are associated with cordierite-biotite-hornfels and, as indicated earlier in the paper, the evidence suggests that the latter series was derived from spilitic types as a result of Fe metasomatism. The cummingtonite-anthophyllite rocks, like many Fennoscandian examples, appear to have been derived from the wall rock adjoining the igneous type as a result of Fe-Mg metasomatism. As already indicated Mg driven from the spilitic rocks during their conversion to cordierite-biotite-hornfels would account both for the introduced Mg, and for the association of, and gradation between, the two rock types. The amphibolites, probably derived from limestone, appear from the literature to occur in association with basic igneous rocks from which part of their materials may have been derived, but more evidence is required on this point. An introduction of Fe from an external source, however, is necessary to account for the Fe metasomatism which resulted in the development of both the cordierite-biotite-hornfels and the cummingtonite-anthophyllite rocks, and also to account for the extraordinarily high Fe content of the amphibolites, and of at least part of the killas.

It is now a well-known fact that the granitization of pelitic sediments and of basic igneous rocks alike involves the removal of at least Fe and Mg. These outgoing constituents have been shown, in other orogenic belts, to have been fixed in amphibolite and skarn developed from limestone and basalt in the frontal zone of granitization (Backlund, 1943), and in zones of cordierite enrichment (Wegmann, 1935). Demay (1937) has recognized such enrichments, in the cordierite-bearing granulites of the Central Massif of France, within the Hercynian belt itself. The marked Fe enrichment of the Cornish rocks, situated in Hercynian times on the margin of the zone of granitization, is probably to be attributed to the fixation of such Fe (driven from adjoining regions of migmatization) which diffused laterally, in the direction of the thrust, through solid rocks. These Fe-enriched rocks, at that time, may well have been covered by the nappe referred to on p. 45. Such an interpretation of the Fe-enrichment in Cornwall is in accord with Backlund's (1943) solution, by reference to ionic diffusion through solid rocks, of the extraordinarily difficult problems connected with the evolution of the Pre-Cambrian rocks of Fenno-scandia.

The petrogenetic importance of the Cornish area lies in the fact that the Fe-enriched rocks are interbedded with rocks of obvious sedimentary origin. The problem is thus not complicated by an intimate association of migmatites and gneisses with the Fe-enriched types, as it is in other regions where such rocks have received detailed investigation. It should, therefore, be possible by meticulous researches on the Cornish rocks, with strict correlation between field observations

and chemical analyses, to reach a completely unambiguous conclusion as to the reality of a large scale ionic diffusion in orogenic zones. That solid diffusion is indeed an active process in regional metamorphism, outside zones of migmatization, is already established by the work of Perrin and Roubault (1941). In making reference to solid diffusion as an active process in rock genesis, it should not be forgotten that as long as 43 years ago, just after experimental work (Roberts Austen, 1900) had shown that gold was able to diffuse into lead whilst both were in a solid state, Greenly (1903) suggested that the permeation-gneisses of Sutherland might be explained as a result of solid diffusion.

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Recent Views on Ice Sheets and Glaciers

BY N. E. ODELL

THE war has cut us off unfortunately from much that has been proceeding in other lands, even in the way of scientific research which was of no military significance. The records of such research are scattered through many periodicals which are not always accessible as yet in this country.

There has recently appeared from the pen of Mr. François Matthes, the well-known head of the Section of Glacial Geology of the United States Geological Survey, an important monograph entitled " Glaciers ". It is published as Chapter 5 in " Hydrology " (*Physics of the Earth's Crust*, ix, McGraw-Hill, 1942) which is edited by Oscar E. Meinzer. This chapter reviews some of the advances made in recent years, more particularly in glaciology as opposed to glacial geology.

A very interesting and carefully documented account is given by Mr. Matthes of the studies lately made in glacier movement, the real nature of which has remained more or less of a riddle—indeed ever since Gruner opined in the last decades of the eighteenth century that Alpine glaciers slid bodily down their valleys. The latter primitive view was adopted and developed by de Saussure, but it was soon challenged and discarded by L. Agassiz, Tyndall, Forbes, Hess, and others. No agreement, however, could be arrived at as to how an apparently solid crystalline substance such as ice could adjust itself in large degree to the irregularities and tortuosity of its channel or valley, and flow as if a plastic or a viscous body. For a long period mainly two rival ideas held the field, viz. J. D. Forbes's theory of viscous flow and Tyndall's hypothesis of fracture and regelation.

Matthes cites the views held by leading modern observers, and pays a special tribute to the fundamental work of the British Jungfraujoch Research party of 1938 under Mr. Gerald Seligman—a classic in recent investigation. It is, however, the notable and often brilliant researches of the young American glaciologist, Max Demorest, that claim Mr. Matthes's particular attention. It is, incidentally, all the more tragic to think that this original investigator's life has been cut short at thirty-two years under heroic circumstances of attempted rescue of an American " flying fortress " crew on the ice-cap of Greenland in November, 1942.

In Demorest's brief career Matthes shows that he had gone a long way towards solving the problem of glacier motion, both in confirming the Jungfraujoch Expedition's findings and in extending them. This is all of great importance, though details of it cannot here be given, suffice it to say that Demorest's concept of glacier movement embodies two distinct modes of flow, viz. (*a*) direct " gravity-flow ", such as occurs typically in valley-glaciers descending unimpeded moderately steep

uniform gradients, and (*b*) what he terms " extension flow ", which is characteristic of ice-sheets and ice-caps, and is induced by differential pressures within those masses. Whilst inter- and intra-granular adjustment probably combined with pressure-melting (the " Thomson effect ") may explain the intimate mode of movement which in aggregate composes the general motion of a glacier, numerous observers have shown that under certain conditions shearing motion and faulting of one ice-mass over another can definitely take place. A particular cause of such shearing is undoubtedly obstruction to free movement of a glacier, which may be localized along restricted zones or planes in the ice. In his study of glacier-mechanics in relation to such conditions, Demorest added two further fruitful concepts of " obstructed gravity-flow " and " obstructed extrusion-flow ", which are found in nature to be more prevalent (except ex-hypothesi under the centre of a large ice sheet) than either simple gravity flow and simple extrusion flow cited above.

In a limited space no details of these distinct types of flow can here be given. Demorest has clearly shown that they are distinctive, though fundamentally of the same nature, i.e. all are examples of streamline flow. Extrusion flow is what he calls " pressure-controlled ", i.e. dependent on the slope of the glacier surface, and the shear stresses are due to differential pressure and differential plasticity. Parenthetically, it should be remembered that plasticity increases in depth in an ice-sheet, and hence the less resistant lower layers must tend to be extruded. Gravity flow Demorest regards as " drainage-controlled ", i.e. dependent on the slope of the glacier floor, and the shear stresses are due to components of gravity. Demorest's original papers and diagrams should be referred to for a clear presentation of the factors involved.

Arising out of Demorest's theory is the idea of higher speeds obtaining in the lower layers of a glacier than the upper ones, under the postulated conditions of plastic flow ; a possibility indeed envisaged earlier, but in rudimentary manner only, by L. Agassiz and Albert Heim, and developed by Reid and Streiff-Becher. It is an intriguing deductive conception, for it offers a potential explanation of many otherwise obscure glacial phenomena. But actual measurement of this flow at depth must be exceedingly difficult, if not impossible, with existing technique ; and herein lies a great opportunity for further important glaciological research.

In Demorest's last paper,[1] published posthumously, which is referred to by Mr. Matthes, much consideration is given to the Greenland ice-sheet, as to its configuration and the highly controversial question of its underlying topography. From the existing data, including the German soundings, Demorest gives it as his considered conclusion

[1] Max Demorest, Ice Sheets, *Bull. Geol. Soc. Amer.*, 54, 1945.

that the ground surface below the ice-sheet cannot be regarded as basin-shaped—a standard view of the isostasists, but rather that a very rugged relief, with high central topography, is much more likely. Here again is an immense field for future research, both in its application to Greenland as well as to Antarctica.

Mention must not be omitted of a matter that has been one of Mr. Matthes's own special studies in recent years, namely the universally prevailing glacier-shrinkage, and whether it is likely to continue and eventually become catastrophic. He reassuringly reiterates the evidence which has been accumulating both in Europe and America to refute the idea of progressive diminution of glaciers and ice-sheets since the last great Ice Age ; namely, that since the latter epoch there has been a long period of climate warmer than the present—the so-called " climatic optimum ", some time between 2000 and 500 B.C. ; and that subsequently we have been undergoing a world-wide deterioration of climate, with revival of glaciers and the establishment of a " little ice-age " or " neo-ice-age " (Matthes's suggested terms), and finally, experiencing only relatively recent amelioration (since A.D. 1850), to give the widespread glacial recession, which may or may not be a continuing phenomenon.

REVIEWS

ÉTUDE PÉTROGRAPHIQUE DES MINERAIS DE FER OOLITHIQUES DU DOGGER DES ALPES SUISSES. By L. DÉVERIN, pp. viii + 115, with 20 plates and 5 text-figures. Lausanne : Imprimerie Baud, 1945.

It is of course well known that on the Continent the name Dogger is applied to the whole Middle Jurassic ; as defined in this work, Aalenian to Callovian inclusive. It is curious how the Cleveland word dogger, applied to any large well-rounded block of stone, has become internationalized, to include all sorts of rocks not in the least like doggers, with also a stratigraphical application.

The author of this work is a devoted disciple of the late Professor Cayeux, and he complains, quite justly, that some of his master's work has been misunderstood. This misunderstanding is attributed partly to the ambiguity of the word " Oolithe " in French and German, meaning both a whole rock (English, oolite) or a single " fish-egg " (English, oolith). To obviate this difficulty he suggests and employs " ovulite " for oolith. This has the drawback of being a Latin-Greek hybrid (ovum and λιθος).

As a consequence of the above-named ambiguity some writers have

assumed that Cayeux meant that oolitic ironstones were formed by direct replacement in their present situation of oolitic limestones. In reality Cayeux's theory was much more complicated than this. In the space here available it is not possible to set out the theory in detail, but the gist of it is that all the ooliths in existing ironstones have been formed and have undergone their evolution somewhere else and have been transported ready made to their present position. It is only the matrix that is authigenic. It follows as a corollary that the ooliths cannot have undergone any changes in the existing rock, where they are as it were hermetically sealed. The minerals are supposed to follow, in their first environment, a definite evolutionary sequence, thus: calcite, siderite, chlorite, limonite, haematite, magnetite. The same considerations apply to originally calcareous organic remains.

In one section Professor Déverin pours scorn on those petrographers who have concluded that chamosite has been precipitated in the sea in a jelly-like form. This question cannot of course be argued out here, but it is an interesting coincidence that the Yorkshire Dogger in the original sense provides much evidence which needs most careful consideration on this as well as on other aspects of the subject of this memoir—such as the significance of siderite as an original and a replacing mineral. Here the relations of chamosite and siderite do not always (or generally) follow the orderly sequence given by Cayeux. Nothing seems to be said about kaolinite, which plays an important part in British ores. Another difficulty presents itself in those not very rare instances where a large number of calcite ooliths, all in optical continuity, are embedded in a matrix of siderite. It seems clear that the last word is very far from having been said on the origin of oolitic ironstones.

In the chapters dealing with the Swiss occurrences, five in number, the author gives a most careful and detailed account of his observations, naturally correlating them with the theory set forth above. These chapters are illustrated by twenty beautiful plates of microphotographs with excellent explanations.

R. H. R.

ON MAJOR TECTONIC FORMS OF CHINA. By T. K. HUANG. 1945 *Mem. Geol. Surv. China*, Ser. A, No. 20, pp. iv + 165, 8 folding maps.

The Chief Geologist of the Geological Survey of China is to be congratulated on achieving such a comprehensive treatment of this subject in spite of the difficult circumstances prevailing in China.

In classifying structural types Dr. Huang follows Stille and Argand

in distinguishing between Alpinotypen or plis neufs, and Germanotypen or plis de fond. He extends the latter group of foundation folds, subdividing it to include folding, warping, and faulting of sediments within areas of eroded fold mountains or continental masses. This is because Chinese mountains are characteristically polycyclic. In naming these successive orogenic cycles, Dr. Huang is more conservative than many of his colleagues and uses the terms : (1) Caledonian ; (2) Variscan, with three cycles from late Devonian to end-Permian ; (3) Indosinian, with two phases, late Trias to Lias ; (4) Yenshanian, with three phases, late Jurassic to end-Cretaceous ; and finally (5) Himalayan, with three phases.

The evidence for and nature of these orogenies is summarized at length, and together with a cursory palaeogeographical reconstruction, illustrated by maps, constitutes more than half the essay. This evidence is occasionally rather thin from the nature of the case. So many areas have hardly been surveyed. The very extensive flysch deposits known as the Sikang series, for instance, to the west of the Kam-Yunnan axis, have been mapped as Jurassic by some. Dr. Huang points to the absence of fossils and suggests pre-Triassic age on other grounds. The reviewer recollects seeing these placed in the Silurian on the basis of some slight palaeontological evidence. This would agree with the finding of unmapped fossiliferous Silurian rocks to the east of the axis. To the north unfossiliferous mudstones of the same facies, the Lifan Series, have been mapped as Jurassic. But Dr. Huang seems alive to the need for re-examining some early mapping.

The general conclusions drawn are such that few would disagree. Deformation is controlled by the differential distribution of strong and weak regions. Geosynclines are the first in order and in intensity of folding. They have, moreover, migrated leaving a corresponding increase of stable continental area behind. Their advance is in halting yet irreversible steps. The Tarim Massif and the Siberian Platform were cemented in the Variscan Cycle to form Pal-Asia. This was joined with Indosinian movements to the Sino-Korean Massif, Chiangnania, and Cathaysia, to form Meso-Asia. Finally the Tethys migrated in stages to the Indo-Gangetic plain leaving Neo-Asia. The direction of migration is southward from Pal-Asia (Angaraland) to India (Gondwanaland). To the east of this there is another migration from the Pacific coast (Cathaysia) to the north-west. In each case the oldland and the foreland are described as those massifs from which and to which the geosyncline migrates. It is surely questionable to conclude " The oldland is active, the foreland is passive. It is from the oldland that the orogenic compression comes ".

Dr. Huang is emphatic that any surface pattern of the mountain chains is entirely determined by the shape and distribution of the

rigid blocks which compress the less rigid areas between them. From this initial distribution certain general trends (Leitlinien) are correlated with times of folding to define major fold systems. These systems are termed (1) Pacific, largely N.E.–S.W., Yenshanian ; (2) Mongolian, N.W.–S.E., and (3) Central Asiatic, E.–W., both comprising the Pal-Asiatic System, mainly Variscan ; (4) Tethys-Himalayan, E.–W. ; and finally two groups, polycyclic and of no constant direction (5) Cathaysia ; and (6) the Kam-Yunnan-Tonkin axis.

The last part of the paper treats igneous activity and mineralization in space and time. Considerable granite formation in the mid-Variscan phase is relatively unproductive of useful minerals in contrast to the Yenshanian mineralization which accounts for most of China's metallic wealth.

Interpreting Chinese structures without discussion of J. S. Lee's well known tectonic types may be regarded as a deliberate alternative emphasis. From Lee we picture a surface film of sediments reacting to a pattern of underlying stresses. T. K. Huang gives us a picture of troops in the front line (geosynclines) suffering the worst punishment (in attack from the massifs). If this analogy be extended perhaps Chinese orogenic history reveals a strangely contemporary style of warfare, with fluid attack and defence in depth concentrating around scattered strong points. We may now wonder whether at last China is achieving a structural unity having pushed off the continuing tectonic struggle to coastal deltas and island arcs.

Many will be grateful to Dr. Huang for making this valuable communication available in the English language.

W. B. H.

SCHEELITE IN NORTH-WESTERN MEXICO. *Bulletins* 946-C and 946-D. United States Geological Survey. 1945.

The heading of this notice does not follow the orthodox bibliographical form, because the titles of the publications are long and cumbrous, whereas the Bulletin number is quite adequate for reference by those interested. The production of tungsten ores from North-Western Mexico, in the provinces of Sonora, Sinaloa, and Baja California is unimportant commercially, but the occurrences show some points of petrological and mineralogical interest, in that all the tungsten occurs as scheelite, even when in pegmatites and quartz veins. The essential feature is a granite-limestone contact, where the formation of scheelite rather than wolfram is of course obvious, along with garnet, epidote, hornblende, idocrase, fluorite, pyrite, molybdenite, and chalcopyrite. There is no cassiterite. A more remarkable fact is

the occurrence of scheelite in pegmatites at a contact of granite and quartzite, with chalcopyrite and molybdenite. Even stranger is the presence of scheelite in quartz veins, with chalcopyrite, molybdenite, and pyrite in a gangue of quartz and calcite. Wolfram appears to be entirely absent, which suggests that there must have been a strange scarcity of iron in the rocks concerned. All this provides an interesting example of a curious type of pneumatolysis, and the detailed descriptions given in the Bulletins seem to show clearly that the granite or its emanations were of a very special type. It is just such special types that are difficult to explain on current theories of granitization, while they are of first-class interest in the theory of ore-deposits.

CORRESPONDENCE

AN ESTIMATE OF THE AGE OF THE EARTH

DEAR SIR,—In a highly interesting paper Holmes [1] gives the remarkably consistent results of age calculations based on the relative abundances of the isotopes in twenty-five samples of lead, as determined by Nier and his co-workers. The outcome is roughly 3×10^9 years. We must congratulate him on having again advanced our knowledge of geological ages by a marked achievement. But I believe it should be emphasized that what has been ascertained is not, as Holmes states, the " age of the earth ", but the " age of the materials forming the earth ". Our conceptions of the birth of the solar system and the earth are vague, but in current opinion the zero time that Holmes has determined would not apply to the earth but to some earlier event, that for convenience might be called the birth of the Milky Way. The subsequent formation of the earth as a separate entity came later and there is no reason for supposing that the clock Holmes has read for us, was set to zero again by that revolution. Hence, the earth is younger than 3,000 million years. The difference need be only a small amount, but it may also amount to a large fraction of the estimated age.

I hope this remark will serve to clarify a minor point in an otherwise lucid and epoch-making contribution from the great time keeper among geologists.

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[1] A. Holmes. An Estimate of the Age of the Earth. *Nature*, vol. 157, p. 680, 1946.

LINEATION IN THE NORTH-WEST HIGHLANDS OF SCOTLAND

SIR,—Study of the lineation in metamorphic rocks of the North-west Highlands of Scotland was initiated by the original geological surveyors, who mapped in many places a " direction of stretching of the particles of foliated rocks ". Analysis of the fabric (Phillips, 1937, 1945) shows that, over a wide area east of the Moine Thrust in rocks originally mapped as belonging to the Moine Series, this south-easterly plunging lineation marks the direction of the *b*-axis of the girdle fabric of a B-tectonite—the lineation is a *Striemung* of German authors. Richey & Kennedy (1939) have demonstrated that in the Morar district an upper series, referred to the Moine Schists, rests unconformably on a lower group containing both ortho- and para-gneisses which they have provisionally named the Sub-Moine Series. Until the mapping of these two divisions is carried further north it is not clear how far the rocks in which I have examined the lineation may belong to the Sub-Moine Series, and it therefore seems advisable at present to refer to these rocks non-committally as " lineated schists east of the Moine Thrust ".

It has been widely accepted by structural petrologists, following mainly the pioneer work of Sander, that a *Striemung* is induced by displacements acting in a direction approximately normal to it, but this correlation has at times been called in question (Martin, 1935, 1936, 1939 ; Strand, 1944 ; Kvale, 1941 etc. ; E. Cloos, 1944, 1946,). A north-west south-east lineation, which is parallel to the *b*-axis of a girdle fabric, is widely developed on the south-east flank of the Caledonides in Norway, and has been interpreted (Kvale, Strand) as a true " direction of stretching " developed during the Caledonian movements ; where it is found in rocks of proved pre-Cambrian age, these rocks are held to have been completely recrystallized during the Caledonian orogeny.

I have recently examined the microfabric of a number of ortho-gneisses and hornblende schists from the Foreland region of the North-west Highlands (rocks which are coloured on the maps of the Geological Survey as Lewisian), and find that here also the lineation is parallel to the *b*-axis of a girdle fabric. The lineation strikes predominantly north-west south-east. It is conceivable that within the Scottish Caledonides there may be included metamorphosed representatives of Lewisian and other Sub-Moine rocks, Moine, Torridonian, and Lower Palaeozoic rocks, and detailed examination of their fabric should help to provide some evidence for their eventual separation. Further research is necessary to establish how far (if at all) the south-easterly plunging lineation of the " lineated schists east of the Moine Thrust " can be correlated with the similar lineations in rocks of the Foreland.

and thus be interpreted as a relict fabric. It is important, meanwhile, to record that there is an extensive development in Scotland of a north-west south-east lineation which apparently *cannot* have been induced by the Caledonian movements, but which must be related to a pre-Torridonian orogeny, since these lineated rocks of the Foreland are overlain by unmetamorphosed Torridonian and Cambrian sediments.

F. C. PHILLIPS.

CAMBRIDGE.
December, 1946.

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CRYSTALLIZATION OF PLUTONIC AND HYPABYSSAL ROCKS

SIR,—I should like to reply to Mr. McIntyre's letter appearing in the last number of the *Geological Magazine*. I will deal with the points he raised in order:—

1. If members of a series of related minerals cease to crystallize out one after the other, a eutectic relationship between the individual minerals is excluded. Obviously eutectics and reaction points can occur in the same system, and a " concealed maximum " is associated with an incongruent melting compound which gives rise to a reaction point in the system. I am afraid I assumed my readers would be familiar with the more elementary types of phase diagram.

2. As Mr. McIntyre is so interested, I can indicate the kind of phase

relationships which *may* be involved. So far as hornblende is concerned they could be those which occur when a compound melts incongruently to give two solid phases (in this case augite and hypersthene) and liquid. This case is dealt with, for a ternary system, by Vogel in *Die heterogenen Gleichgewichte*, 1937, p. 446. So far as augite and hypersthene are concerned, they might crystallize out together simultaneously along the boundary curve between their respective fields ; or the shape of the boundary curve might be such that one of its tangents passed through the composition of augite, the point of tangency dividing the curve into two parts, one of reaction, and one of simultaneous crystallization.

3 & 4. It is not meant to infer that the final residual liquid in differentiation contains nothing but Ca-Na-K alumina-silicates but such compositions are so closely approached that their position in what Bowen refers to as the imaginary polydimensional space diagram, is substantially determined by the equilibrium relations in the Or-Ab-An-Qz diagram. The position is similar to that in, say, the system leucite-diopside-silica, where the ternary eutectic orthoclase-diopside-silica contains so little diopside that little error would be introduced by considering the binary eutectic orthoclase-silica in its place. Strictly speaking the line representing the crystallization period of biotite in my diagram should be extended to the end on the right hand side, and the words " ceased crystallizing " as applied to biotite should read " ceased crystallizing to all intents and purposes ".

5. I do not state that the crystallization curve for the light constituents, determined by study of the rocks, coincides with the theoretical curve followed by a liquid in contact with all its early crystals. The only time I specifically draw attention to the form of the curve is when it has been projected into the system Or-Ab-An, when I state that it corresponds " *with a moderate but not particularly strong degree of fractionation during crystallization* " (p. 215). Naturally the liquid at any stage is in contact with some of the earlier formed crystals. The latter do not all sink like stones to the bottom of the magma chamber the moment they are formed. The whole point is that the liquid is not in contact with *all* its earlier formed crystals, and this is exactly what a moderate degree of fractionation implies. Far from being conclusive evidence that differentiation did not take place by separation of early crystals from the liquid, it shows that a certain amount of such separation must have occurred.

6. The relations between granite-pegmatites and aplites will be dealt with further in a forthcoming paper. The point I tried to make was that the phase boundaries determined in a dry melt system are not applicable without any change in position to a watery solution containing the same components.

7. Yes, I think in some cases only a small amount of magma is required, just sufficient to lubricate the crystal aggregate and allow it to intrude.

8. Only someone already prejudiced against the hypothesis of magmatic differentiation could conclude that the results given in my paper show " that a magmatic interpretation of the Scottish Caledonian complexes cannot be reconciled with the firmly established principles of phase-rule chemistry ". The facts brought forward in connection, more especially, with the light constituents indicate a most striking similarity of behaviour between these constituents in natural magmas and in experimentally determined melts. Is it an accident that the last residual liquids of natural magmas should lie on the ternary cotectic curve ? This affords a rational explanation of the composition of the aplites and their related lavas and explains why rocks of more extreme acid character are not found here or in other igneous rock series. The hypothesis of emanations does not explain this limitation of composition nor does it explain the fact that lavas and dyke rocks, belonging to the same suite, have the same chemical composition as plutonic rocks lying on the assumed liquid line of descent.

It is interesting to learn that Mr. McIntyre has been investigating the Loch Doon complex, but hardly surprising to find him concluding it has been formed by metasomatic replacement, in view of the address given at the bottom of his letter. I cannot feel this to be an argument against the hypothesis of magmatic differentiation.

In conclusion, it is gratifying to find an emanationist taking some interest in phase diagrams, even if in a rather naïve fashion. If only Mr. McIntyre can persuade his fellow emanationists to do likewise, there may come a day when the emanationist view of the origin of rocks can be discussed as a reasonable scientific hypothesis.

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CHILLED AND " BAKED " EDGES AS CRITERIA OF RELATIVE AGE

Sir,—In their recent letter to the *Geological Magazine*, Dr. Richey, Dr. Stewart, and Professor Wager record the fact that on Glamaig, on Sron a'Bhealain, and in Allt Daraich, in the Red Hills of Skye, they have found marscoite to be chilled against the granophyre with which it is in contact. They interpret this evidence as proof that the marscoite layer is younger than the adjacent granophyre. On equally good evidence, however, i.e. the inclusion of relics of marscoite within the granophyre of these localities, Harker (*Skye Memoir*, 1904,

pp. 187–196) came to the opposite conclusion, deducing that the marscoite was older than the granophyre. The latter he considered to have replaced much of the basaltic rocks within which the marscoite originally formed layers.

When reliable observers disagree on what appears to be such a straightforward issue as the relative ages of adjacent igneous rocks, it is clear that the criteria on which the conclusions are based require re-examination, and that such further consideration may well lead to an important discovery. Since one of us (D.B.McI.) spent several weeks examining the rocks of Glamaig, Sron a'Bhealain, and Allt Daraich last spring, and since the other (D.L.R.) is investigating the Tertiary rocks of Slieve Gullion, where similar problems are presented, it is perhaps not out of place for us to make some of our observations available.

On Slieve Gullion thick layers of dolerite alternate with sheets of granophyre against which the dolerites develop fine-grained edges. At some localities these fine-grained edges have a variolitic texture, and are characterized by skeletal crystals of plagioclase similar to those found within the tachylytic selvedges of members of the younger dyke swarm. This evidence clearly indicates that the fine-grained edges of the dolerite layers are chilled edges. There is, however, another line of evidence suggesting that these fine-grained edges have been " baked ". Not only do the plagioclase crystals they contain exhibit " clouding ", of the type so commonly interpreted as indicative of contact alteration, but in places the texture of the margins is distinctly hornfelsic. In this case the pyroxene is crystalloblastic, occurring as granules or as more robust stellate forms to which Dr. Richey has applied the term " star aggregates " (*Proc. Geol. Assoc.*, 1937, p. 274). Such " baked " margins, however, still retain evidence that they originated as a result of chilling, for not only does the grain-size of the rock decrease as the contact with the granophyre is approached, but some of the larger plagioclase crystals within these hornfelsed margins still retain their original skeletal form. Paying attention to one set of criteria, Dr. Richey has interpreted these selvedges as " baked edges " (*Proc. Geol. Assoc.*, 1935, p. 488 ; 1937, p. 274), whilst one of us (D.L.R., *Proc. Geol. Assoc.*, 1937, p. 255), paying attention to the other set of criteria, has interpreted them as chilled edges. The only interpretation that will satisfy all the criteria, however, is that the edges are chilled edges that have been subsequently " baked ".

Now it is clear that these fine-grained selvedges of the dolerite layers cannot have been both chilled against the adjacent granophyre and " baked " by it. It has, however, already been shown (D.L.R., *Proc. Geol. Assoc.*, 1937) that the granophyre at one horizon on Slieve Gullion has been developed in situ from Caledonian granodiorite, and

that the transformation has culminated in rheomorphism, as is witnessed by the veining of the dolerite by the granophyre. Thus, in their present forms, both the dolerite and granophyre layers are, so to speak, " metamorphic " rocks. The only logical interpretation, therefore, is that the dolerite layers were originally emplaced and chilled against the antecedents of the present-day granophyre layers, and that the whole rock suite was subsequently " baked ", this process accounting both for the hornfelsic texture of the dolerite and for the rheomorphism of the granophyre, that is, of the rock with the lower melting point. Such changes in the initial layered rocky pile are perhaps not surprising when it is realized that the rocks under discussion occupy the site of what may well have been a caldera within the area enclosed by the Tertiary ring-dyke of Slieve Gullion.

Although in a different milieu, such co-ordinated changes in diversified rock assemblages are comparable with those observed by Sederholm in the Pre-Cambrian rocks of Finland. After an initial granitization of the leptites of Svionian age, which resulted in the development of grey gneissic granite and its associated migmatites, a swarm of dolerite dykes was intruded. These dykes commonly show chilled edges against the older rocks. Subsequent changes led to the conversion of much of the grey gneissic granite and leptites, which formed the country rocks of the dolerite dykes, to the younger Hangö granite. Within the Hangö granite the dolerite dykes now occur as hornfelsed, amphibolitized, and veined relics, yet some of them still retain fine-grained margins which originated as chilled edges against the antecedents of the red Hangö granite.

Now it will be clear from the above discussion that the finding by Dr. Richey, Dr. Stewart, and Professor Wager that the marscoite has chilled edges against the granophyre can be accepted as a criterion of age only if it can also be shown that Harker's observation—that the same marscoite occurs as inclusions within the granophyre—is wrong. One of us (D.B.Mc.I.) was fortunate in visiting the localities in question during last May and June when the burns were exceptionally low, and not only was Harker's observation that inclusions of marscoite occur within the granophyre of Allt Daraich confirmed, but a complete set of specimens was collected, varying from marscoite through net-veined marscoite, " spotted granophyre " and dark granophyre, to relatively leucocratic granophyre, to illustrate all the stages of disappearance of the marscoite within the granophyre. The marscoite of this locality was found to be fine-grained where it is in contact with the granophyre, but equally fine-grained patches were also found well within the mass. The sheet-like body of marscoite outcropping on Sron a'Bhealain, of which, as Harker suggested, the exposure in the Allt Daraich probably forms a continuation, has a chilled margin as Dr. Richey, Dr. Stewart,

and Professor Wager record ; the selvedge is, in fact, tachylytic. At the same time the following observations made by Harker—apparently inconsistent with the chilling—were confirmed : "the sheet [of marscoite] itself is seen to be two-fold, with a parting along which the acid magma has found access. Both in this parting and below the base of the sheet the acid rock is crowded with partially digested xenoliths of marscoite." Thus the Allt Daraich–Sron a'Bhealain sheet of marscoite is seen both to be chilled against the granophyre and to occur as inclusions within it. The analogy with the previously discussed examples from Northern Ireland and Finland will be obvious.

On Glamaig and Sron a'Bhealain and in Allt Daraich, Dr. Richey, Dr. Stewart, and Professor Wager distinguish an older biotite-hornblende-granite and a younger "spotted" granophyre. The reason for this distinction is not obvious. Locally the granophyre of the area under discussion is leucocratic, adjacent to marscoite it contains hornblende and biotite, and in places it is spotted with marscoite in association with which it may contain quartz xenocrysts derived therefrom. Moreover, in contact with the gabbro relics in the Allt Daraich it contains monoclinic pyroxene. Throughout its varietal facies, the granophyre exhibits a micropegmatitic texture.

Far from providing a simple interpretation of the age relations of the rocks of Glamaig, Sron a'Bhealain, and Allt Daraich, such as is proposed in the letter under discussion, the facts are actually more complicated than even Harker's descriptions would indicate. Further complications are that in the Allt Daraich and on the slopes of Glamaig the granophyre contains abundant inclusions of fine-grained granophyre ; other inclusions are pyroxene-bearing, whilst yet others appear to be of sedimentary origin. Some of the basalts near the granophyre contact on the summit of Glamaig contain patches, two or three feet across, with numerous plagioclase phenocrysts, and similar patches are found within and near the base of the marscoite sheet on Sron a'Bhealain. The porphyritic patches in the marscoite contain very peculiar sheaf-like aggregates of strongly coloured monoclinic pyroxene. This pyroxene is identical with that characterizing the gabbro of Allt Daraich. Moreover, patches of gabbro, additional to those recorded by Harker, were found in the granophyre, unassociated with marscoite. Another point of interest is that the marscoite contains small fine-grained basic inclusions which themselves contain rimmed quartz xenocrysts similar to those found in the marscoite.

The rocks of the marscoite areas evidently constitute a palimpsest, from which a complex succession of histories remains to be deciphered.

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The Genesis of some Micro-Veinlets in Cornish Granite-Porphyry [1]

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(PLATES I AND II.)

WHILE studying the Cornish mineral deposits I have examined certain thin-sections cut from granite-porphyry dykes which contain numerous quartz or felspar veinlets. The structures in these veinlets and their behaviour towards the various constituents of the host rock are, I believe, sufficiently interesting to merit detailed description. The sequence of events to be deduced from these features is not commonly recognized, and the underlying principles may have a broader application to include some of the larger mineral veins in Cornwall.

Porphyry dykes, several feet wide, are common in many parts of the county, where they occur in both sediments and granite. The granites, porphyries, and tin veins form a genetic series and, in the majority of cases, were formed in that order. The relationship between them is exceedingly close and porphyry dykes are commonly exposed during mining operations. All rocks in centres of tin mineralization are frequently veined by later mineral depositions. Such is the case at South Crofty Mine in the Carn Brea area ; three or four porphyry dykes are exposed underground and sections cut from one of them provided the material for the first part of this paper.

This particular porphyry is a hard, greenish-grey to brown dyke-rock composed of phenocrysts of orthoclase, quartz, and biotite set in a very fine-grained felsitic groundmass. The rock has been slightly altered by secondary processes resulting in sericitization, kaolinization, and chloritization. Specimens were collected from an exposure on the 260-fathom level about 1,100 feet north of Robinson's Shaft.

[1] Micro-sections described in this paper were prepared with the assistance of part of an award from the Parliamentary Grant in aid of Scientific Investigations administered by the Royal Society.

The dyke is only exposed in the main crosscut several yards north of the No. 4 Lode. It is in granite, about 175 feet from the granite/slate contact. The granite porphyry is cut in places by numerous sets of sub-parallel veinlets (Pl. I, fig. 1). These invariably consist of either quartz or felspar—there are no veins of a mixed nature—and wherever the two types intersect, the felspar veins appear to be the older. There is no noticeable wall-rock alteration connected with these veinlets.

The Quartz Veinlets

These range from 0·02 to 0·3 mm. in width and form a conspicuous sub-parallel group. Where they traverse the groundmass they characteristically show sharp contacts even under the microscope (Pl. I, figs. 1 and 2).

They are fairly regular in strike and width, broken by an occasional sudden indentation (Pl. I, fig. 2, top right, and the wide vein in fig. 1). Generally speaking, however, the walls may be said to match. A comb-structure is well developed, especially in the wider veins. Under ordinary light this is beautifully emphasized by concentrations of minute inclusions in the vein outlining the form of prismatic quartz crystals which had formed a crustified band on both walls, the crystals projecting into the vein. A perfect hexagonal basal section of quartz can be seen in the main vein where the smaller veinlet branches off (Pl. I, fig. 2). Under polarized light it is evident that the deposition of quartz had continued in optical continuity with the crustified quartz, but the mutual interference of the crystals in the later stages of vein formation resulted in a less regular final texture. Nevertheless, over 80 per cent of the vein-quartz is orientated with the *c* axis roughly perpendicular to the vein walls.

These quartz veins, when traversing the groundmass of the porphyry, are remarkably free from other mineral constituents. An occasional small grain of apatite, mica, or chlorite may be present, but these are considered to have originated in the groundmass, as can be proved by a study of the few shreds and pieces of groundmass enclosed in the vein. There is often a very narrow zone on the vein-walls where vein-quartz has grown at the expense of the groundmass, and it can be seen here that white mica and chlorite are the last minerals to be replaced. One very narrow vein contained irregular grains of fluorite as an original constituent. This mineral is also sparingly present in the groundmass where it was formed by secondary replacement processes not apparently connected with the veinlets. The numerous " pepper-dust " inclusions mentioned above are too small to be determinable ; some are opaque, others translucent with a high relief.

The most important feature shown by these veins in the groundmass is the evidence for early crustification along the walls of the veins. Metasomatic processes can give rise to simple banding, but it is difficult to see how they can give rise to comb-structure and crustification. This type of crystal growth was regarded by Posepny (1893, p. 207) as proof of cavity filling, but Church (1893, p. 596) and Becker (1893, p. 603) asserted that it could be simulated by metasomatic processes. Irving (1911, p. 651), however, supported Posepny and considered that true crustification could be distinguished from banding sometimes formed by metasomatism. Since then many authorities (Lindgren, 1933 ; Emmons, 1940 ; Bateman, 1942) have accepted true crustification as proof of cavity filling, or, to put it another way, crystal growth from a wall into a free space.

The growth of crystals from the walls and the other features of the veins which I have described—sharp contacts, regular width, and the apparent correspondence of opposite walls—are those commonly seen in a vein formed by the filling of an open space caused by separation of the walls of a fissure. Yet this apparently simple interpretation cannot be reconciled with the behaviour of the veins where they intersect the phenocrysts of the porphyry. Such intersections are considered in detail under the following headings :—

(*a*) *Quartz phenocrysts intersected by quartz veins.*

The quartz phenocrysts may show good crystal form (bipyramidal with or without subordinate prism faces), but many were somewhat corroded before the groundmass consolidated. Other minerals included within the quartz are chloritized biotite (often associated with a little iron oxide and small euhedral tetragonal needles of a mineral with high refractive index and birefringence), very occasional grains of kaolinized felspar and small apatite crystals. Numerous mineral inclusions are often present which are too small to determine ; they are opaque or clear and isotropic, and some of the latter contain a fixed or movable bubble. The contact between phenocryst and groundmass is sharp, though in some cases it is very finely irregular. There is no disturbance of the groundmass near the phenocrysts.

Normally these phenocrysts show no strain effects except where they are intersected by the late quartz (or felspathic) veinlets. Here it is seen that they are traversed by a zone of irregular undulose extinction (Pl. II, fig. 3). In thin section the plates of this mosaic pattern are elongated subparallel to the strike of the vein. The optic reorientation of the quartz in this zone is slight and the unstrained phenocryst on either side is optically continuous. This effect can thus be observed only when the stage is rotated with great care ; where small veins are involved, it may only be just discernible or apparently absent. It is,

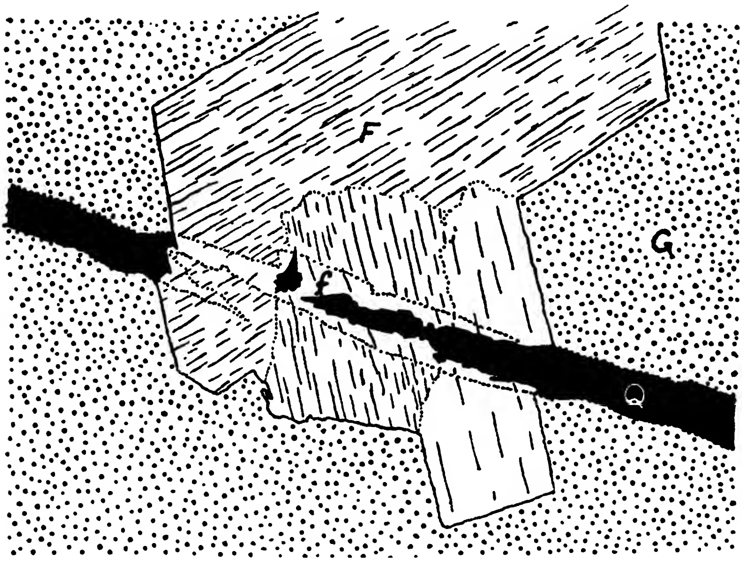
however, a fact that the strike of the vein can be traced across quartz phenocrysts through zones of undulose extinction. These zones are generally somewhat wider than the vein on either side and are less sharply defined. Furthermore, large inclusions in quartz phenocrysts are not seriously disturbed when they occur within one of these strain zones. The peculiar inclusion illustrated in Pl. II, fig. 3, is composed of an irregular mat of chlorite with patches of fine white mica, some iron oxide, and a crystal of the undetermined prismatic mineral mentioned above. Similar inclusions of chlorite and white mica occur in other quartz phenocrysts which are not intersected by veinlets. Also, compared with the unstrained quartz phenocrysts, there may be more, or less, of the minute inclusions in the strained zone. These resemble the normal inclusions of the unstrained phenocrysts and not those characteristic of the vein-quartz when the latter traverses the groundmass. It is sometimes noticeable that a small part of the vein adjacent to the phenocryst is composed of quartz in optical continuity with the latter. It would, of course, be expected that the growth of late quartz would be influenced in the immediate vicinity of pre-existing masses of the same mineral. It must also be pointed out that the vein maintains its normal width right up to the phenocryst and on either side of it. Sometimes the vein is not identical on either side of the phenocryst, but there is never any significant narrowing or broadening of a vein on approaching a phenocryst.

The preservation of original inclusions in the strained zones crossing quartz phenocrysts proves that no disruption has taken place. But the veins on either side were formed by filling an open space. If this opening had been formed by separation of the walls, then there should be evidence of (*a*) readjustment between the phenocryst and the groundmass, or (*b*) a narrowing of the vein adjacent to the phenocryst, which is strained but otherwise undisturbed. Neither of these expectations is fulfilled. The only valid interpretation left open is that the porphyry was slightly sheared along closely spaced parallel fissures in certain well-defined zones, and that free space was formed in the groundmass by removal of material from these zones. This conclusion is further strengthened by features shown at intersections of the quartz veins with felspar phenocrysts.

(*b*) *Felspar phenocrysts intersected by quartz veinlets.*

The felspar phenocrysts are dominantly non-perthitic or but feebly perthitic with no trace of "cross-hatch" twinning. The felspar is probably sodic orthoclase. Considerable kaolinization sometimes accompanied by sericitization and chloritization, is the rule, and enclosed minerals include blebs of quartz, apatite, and, more frequently, chloritized biotite flakes.

Quartz vein intersections with felspar phenocrysts are shown in Pl. I, figs. 1 and 2; Pl. II, fig. 3; and Text-figs. 1 and 2. In Pl. I, fig. 2, the following features are to be noticed: (*a*) the felspar bordering the quartz is clear of kaolin, and (*b*) the clear felspar projects into the vein, as shown by the Becke line. Furthermore, except for slight strain effects, all the felspar is optically continuous. The vein quartz

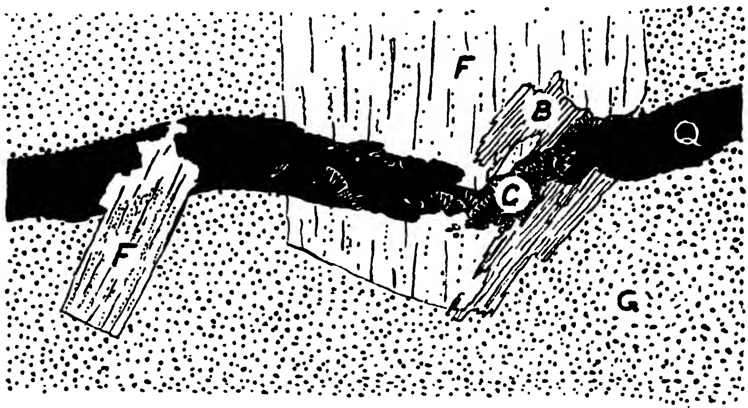


TEXT-FIG. 1.—A quartz vein intersection with the felspar phenocryst also illustrated in Pl. I, fig. 1. The felspar (*f*) between the dotted lines parallel to the vein is clear of kaolinization, and though slightly strained is essentially optically continuous with the phenocryst. G = Porphyry groundmass; F = Felspar; Q = Quartz vein. (× 62.)

consists of an unstrained, granular aggregate. Of greater interest is the felspar shown on the right in Pl. I, fig. 1, and drawn in Text-fig. 1; again (*a*) all the felspar units retain their optical orientation on passing through the vein zone, (*b*) except for a tongue at the left-hand end, the felspar in this zone has been cleared of kaolin, and (*c*) the quartz in the phenocryst is a clear, unstrained, granular aggregate. But the vein is not continuous through the felspar, which has been sheared along a series of subparallel ultra-microscopic planes in the vein zone. The felspar in the vein zone is strained in a manner similar to the quartz phenocrysts. The amount of displacement along any one plane is small, but the cumulative effect results in an appreciable offsetting of the felspar at the limits of the vein zone. Replacement

of felspar by quartz was more active on the right-hand side of the phenocryst.

Text-fig. 2 (left) shows the corroded end of a small felspar phenocryst cleared of kaolin where it passes into the vein. The larger crystal with the intergrown altered biotite has been intensely attacked. The intergrown biotite is rumpled and converted to chlorite in the vein zone,



TEXT-FIG. 2.—The intersection of felspar phenocrysts by a quartz vein. G = Porphyry groundmass; F = Felspar; B = Chloritized biotite; C = Chlorite; Q = Quartz vein. (× 40.)

but it is not cut through by a veinlet of quartz. All minerals intersected by the vein remain optically continuous on both sides of it.

It might be considered that disruption of the felspar phenocrysts had taken place and the fissure filled with solutions carrying abundant silica but only a little potash and alumina. Felspar was thus only deposited where fractured felspar phenocrysts outcropped on the walls of the fissure. The following evidence disproves this contention :—

(*a*) The restriction of the streaky strain effects to felspar in the vein zone, coupled with the fact that adjacent vein-quartz is unstrained.

(*b*) The sudden loss of crustification when the quartz vein passes through the phenocryst (Pl. I, fig. 2).

(*c*) The felspar mentioned in the previous item is shown also in Pl. II, fig. 3 (left-hand edge), wherein it is seen to be near a quartz phenocryst that could not have been disrupted (see p. 68).

(*d*) There is no felspar in the veins when they traverse the felsitic groundmass, despite the fact that some pre-existing felspar must have outcropped on the wall of any fissure.

(*c*) ***Biotite phenocrysts intersected by quartz veinlets.***

Beside the biotite mentioned above, only one other case of a quartz vein intersecting a biotite phenocryst was seen (Pl. I, fig. 1, bottom left). Here the main vein is cut off sharply by the green biotite. A smaller vein cuts through above this point and widens out on the other side in line with the main vein.

From the evidence given above it is reasonable to conclude that :

(*a*) The quartz, orthoclase, and biotite phenocrysts have not been pulled apart along the vein zone.

(*b*) They have been strained in these zones and ultramicroscopically fractured.

(*c*) Solutions penetrated along these fractures. These solutions left pre-existing quartz unaffected ; cleared earlier alteration products from felspar, and replaced it to varying degrees ; and completed the chloritization of biotite but seldom corroded it.

The Felspar Veinlets

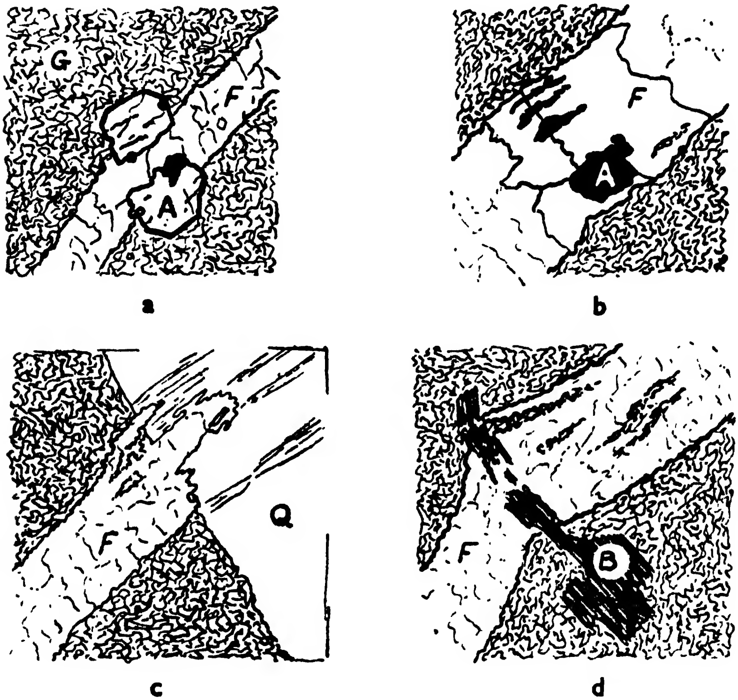
I do not intend to deal with these veinlets in detail, although they are equally as interesting as the quartz veinlets. It will suffice to indicate their essential characteristics. These veins, though generally somewhat narrower than the quartz veins, are also comparatively regular in strike and width. The only vein material introduced is potash felspar, with a refractive index similar to the felspar phenocrysts and no well-developed twinning. Where it traverses the groundmass the vein is composed of irregular prismatic crystals of felspar, 90 per cent of which have grown perpendicular to the vein-walls (Pl. II, fig. 1). Shreds of the groundmass may be preserved in the veins.

At intersections of these felspar veinlets and quartz phenocrysts, the veinlet may penetrate into the quartz for a short distance (Pl. II, fig. 1 ; Text-fig. 3*c*). As in the case of the quartz veins, veinlets can often be traced across these phenocrysts by a shear zone. This zone may contain small blebs of orthoclase. The distribution and irregular contacts indicate that the felspar penetrating the quartz phenocrysts and the included blebs mentioned above were formed by replacement of the quartz. Orthoclase phenocrysts crossed by the vein remain in optical continuity or may be slightly sheared. Also, they may be to *some extent* cleared of alteration products (Pl. II, fig. 2). Biotite may not be affected except for a slight crumpling of the cleavage flakes (Pl. II, fig. 2, left). In some cases, however, a little disruption may have taken place (Text-fig. 3*d*).

Interesting intersections with apatite crystals are shown in Text-figs. 3*a* and 3*b*. Some replacement is indicated and, if pulling apart of the walls did occur, it obviously does not account for the full width

of the vein. This remark applies also to the biotite mentioned above (Text-fig. 3*d*).

The conclusions which may be drawn from these features resemble in many ways those deduced for the quartz veins (see p. 70). In this



TEXT-FIG. 3.—*Felspar Veins*: F = felspar veinlets; A = apatite; B biotite; Q = quartz phenocryst; G = porphyry ground-mass. (All diagrams × 85.)

(*a*) If the gap between the two halves of the apatite crystal represents mechanical separation, the movement could not have accounted for the full vein width.

(*b*) Residual shreds of apatite in the felspar vein.

(*c*) Penetration of a quartz phenocryst by felspar within the strain zone. Irregular blebs of felspar also occur in this zone further into the phenocryst.

(*d*) Note the shreds of groundmass in the vein.

case also, there has obviously been no simple separation of the walls to form an open fissure subsequently filled with felspar. Admittedly, there could have been some disruption in the case of the biotite and apatite shown in Text-figs. 3*a*, *b*, and *c*. Even here it could not account for the full vein width, and no disruption took place in the phenocrysts shown in Pl. II, fig. 1, and Pl. II, fig. 2. There is, therefore,

much evidence for selective attack on the porphyry along narrow zones of ultramicroscopic fissures. Pre-existing quartz and orthoclase were slightly affected, and biotite hardly at all. It might be doubted whether the orientated vein felspar in Pl. II, fig. 1, could have grown by metasomatism, but no conclusive evidence to the contrary is forthcoming. Certainly these veins did not originate in fissures formed *simply* by separation of the walls.

Discussion

We have seen that the features shown by the quartz veins (and possibly the felspar veins also) indicate that they were formed by cavity filling, in the groundmass. On the other hand, where the quartz veins traverse felspar phenocrysts, they appear to have formed by metasomatic replacement. Similarly, the felspar veins have metasomatically replaced quartz phenocrysts to some extent. In many cases it seems clear that there was no separation of the walls of a simple fissure, and even where such pulling apart may have taken place (Text-figs. 3*a*, *b*, and *d*) the movement does not account for more than 30 per cent of the vein width.

In order to arrive at an explanation of the origin of these veins it is necessary to inquire a little into the mechanism of replacement. As Bateman (1942, p. 94) has stated, very little is known about the precise nature of this process, although the results have been studied very thoroughly. An important factor is that exchange appears to take place substantially on a volume for volume basis. Where one mineral or mineral aggregate replaces another by "*an essentially simultaneous*[1] molecular process of solution and deposition" (Lindgren, 1925, p. 247), then this is metasomatism or metasomatic replacement. The minutest structures of the replaced material may be preserved in the metasome, thereby indicating that there can only be a thin film of solution at the replacement front. Nevertheless, it is perhaps logical to look upon the replacement front as consisting of two fronts, a solution front and a deposition front. For metasomatic replacement these two fronts must be very close together and advance at the same velocity. Although little is known about the relevant aspects of capillary chemistry, it is probable that the laws governing the processes make it usual for deposition to be essentially simultaneous with solution. Opinions regarding the nature of the processes have been given by Lindgren (1900, 1912, 1925), Goldschmidt (1922), Boydell (1926), Bain (1936), and others.

However, many contributors to this subject of metasomatism point out that under certain circumstances solution may run ahead of deposition (Lindgren, 1925, p. 250), Emmons (1940, p. 258). Lindgren

[1] Italics are the author's.

(1900, p. 584) draws a line with "Where there were two solutions—one dissolving, the other depositing—and where a certain time intervened, the process is a mechanical one and should not, I think, be considered metasomatism". In the case of solution-cavities in limestone filled at a later date by deposits from solutions entirely disconnected in origin with those which formed the cavities, the process is obviously far removed from metasomatism. The exchange is, nevertheless, on a volume for volume basis; it is "replacement" in two disconnected stages. But a case can be conceived which is not so clear cut. Consider a fissure in which the earlier solutions, by virtue of their condition, concentrate their activities on removal of material from this zone by solution and other means. The flow may be continuous, but with changing conditions deposition may start and become more and more important. Where non-homogeneous material is involved, both removal and deposition may be selective, and locally solution and deposition fronts may nearly coincide and metasomatism take place. It is considered that such a sequence of events would account for the features shown by the quartz veinlets described in this paper.

The granite-porphyry was traversed by narrow zones made up of numerous sub-microscopic fissures, similar to those indicated where the zone traverses the quartz phenocryst in Pl. II, fig. 3. The fissure system was probably most complex in the fine-grained groundmass. Solutions moved in and their effects were largely confined to these fissure zones. I have described a similar localization of reaction from the Carn Brea area, but in that case metasomatic replacement was the dominant process (1946, p. 184). It is not illogical to assume that the first wave may have contained a concentration of hyperfusible constituents which could form the vanguard of any influx of solution by virtue of their greater mobility. Also, the earlier solutions may have been at a comparatively high temperature. Their nature may, in fact, have favoured solution rather than deposition. Their action on the fractured, fine-grained groundmass was selective; the phenocrysts were not so profoundly affected. In this way open spaces were formed in the fissure zones in the groundmass. When the solutions, perhaps at a lower energy level or containing higher concentrations of silica, started depositing quartz, free space was available in the groundmass fissure zones. Deposition would start from the walls and give rise to a band of crustified quartz. Later, metasomatic replacement, principally of felspar, took place. Similar conditions prevailed in the case of the felspar veins, but here metasomatism may have been comparatively more important as a vein-forming process.

The amount of lag between the solution and deposition fronts in the quartz veins cannot be assessed. However, it is probable that the

quartz veins and the felspar veins were formed during the closing stages of plutonic activity ; also, the felspar veins were formed before the quartz veins. It is unlikely that, subsequent to felspar vein-formation, one fluid effected solution and was followed at a later date by another not connected with it, which deposited the quartz vein filling. The solutions involved may be considered as being two of different character—one dissolving, and one precipitating—but it is most probable that there was a continuous flow under changing conditions. The veinlets have been formed at the expense of pre-existing material without any appreciable change in volume. They are, therefore, " replacements "—but not formed by " metasomatism " as defined by Lindgren.

" Metasomatism " and " replacement " have, hitherto, been used synonymously, but as pointed out by Douglas, Goodman and Milligan (1947, p. 546), replacement probably involves more than one process. These authors have retained the synonymity between metasomatism and replacement, and have subdivided the phenomena into " hydrodynamic replacement ", " chemical replacement ", etc. But " metasomatism " refers to a well-established process rigidly defined by Lindgren as " an essentially simultaneous, molecular process of solution and deposition by which, in the presence of a fluid phase, one mineral is changed to another of differing chemical composition " (Douglas's " chemical replacement "). I believe that this is what " metasomatism " means to most geologists, and it would, therefore, be unwise to redefine the term. For these reasons, it is suggested that " replacement " should cover all processes whereby one mineral is changed into another of different composition in the presence of a fluid phase, generally without appreciable volume change—and that " metasomatism " or " metasomatic replacement " be restricted to that common case where such a change is effected by " an essentially simultaneous, molecular process of solution and deposition ".

Quartz Veinlets in the Prah Sands Porphyry

This granite-porphyry outcrops on the shore at Prah Sands, near Marazion, Penzance. The dyke is intruded into metamorphosed sedimentary rocks in the vicinity of the Godolphin granite ; tin and copper lodes have been worked in this area. This granite-porphyry resembles the South Crofty dyke, but it is considerably more altered.

The quartz veinlets in this rock have a more conventional origin, but even so they show certain interesting features. Open fissures were formed by separation of the walls of a crack and crustified quartz was deposited therein where the vein passes through both groundmass and felspar phenocrysts. The vein quartz is optically continuous

with any quartz phenocryst it crosses, but a study of the severe strain effects and quartz inclusions shows that actual disruption took place. The interesting fact is that these veins suddenly swell out in places in the groundmass. These cavities may be vuggy, but the deposit consists entirely of perfect crustified quartz. The cavity must, therefore, have been formed by solution before the quartz was deposited. The setting is similar to that of the South Crofty veinlets, and it appears unlikely that these solution cavities were necessarily formed by solutions entirely unconnected with those which deposited the quartz. It is more probable that the first flow of solution favoured removal of material and with changing conditions quartz deposition became more important.

Conclusions

(1) The evidence is considered to indicate the following sequence of events during the period of vein formation in the South Crofty porphyry :—

(*a*) Close fracturing of the porphyry with very minor separation of the walls at places, followed by circulation of felspar-rich solutions. These formed the felspar veins by fissure filling and metasomatic replacement of the wall rock, preceded in places by minor solution of the porphyry. Phenocrysts were attacked less.

(*b*) Formation of narrow zones of submicroscopic fissures without separation of the walls. Siliceous solutions moving up these zones concentrated their activities on solution of the porphyry groundmass during the early stages. Eventually deposition started with a crustified band of quartz on the walls. During the later stages of vein formation the phenocrysts were metasomatically replaced to varying degrees.

(2) It is suggested that these veins are the result of a series of connected processes, whereby quartz was deposited at the expense of the porphyry, without any appreciable change of volume, and that solution and deposition were not simultaneous. These deposits should, therefore, be considered as replacements, but not as metasomatic replacements. " Metasomatic replacement " should be restricted to the process defined by Lindgren (1925, p. 247).

(3) In the case of the veinlets in the Prah Sands porphyry, emphasis was placed on deposition in fissures formed by mechanical separation of the walls, but again early solution took place at certain points.

(4) The comparable sizes of the veins, phenocrysts, and groundmass grains are responsible for the clear evidence described in this paper. Nevertheless, as a factor in vein formation, early solution followed by deposition brought about by changing conditions in the vein zone is not an illogical conception, and may be of more general occurrence.

While realizing the dangers of unwarranted extension, it is considered that the application of this principle to certain other Cornish veins, showing anomalous characteristics of fissure filling and metasomatism, should be borne in mind when investigating their origin.

Acknowledgments

The author wishes to express his appreciation of the facilities provided by Captain C. V. Paull and his staff at South Crofty Mine, and his gratitude to Professor H. H. Read and Doctors R. M. Shackleton and A. J. E. Welch, for valuable criticism and suggestions. A specimen from the Prah Sands granite-porphyry was kindly loaned by Mr. T. C. Bagchi and thanks are due to Mr. J. A. Gee for his work on the photomicrographs.

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EXPLANATION OF PLATES

Plate I

Fig. 1.—The veinlets marked " Q " are quartz veinlets ; all others are felspar veins. " B " is a chloritized biotite phenocryst. (× 15.)

Fig. 2.—Note the crustification in this quartz veinlet and the Becke line showing the contact between quartz and felspar in the kaolinized phenocryst. The light mineral on the bottom edge is part of a large quartz phenocryst. (× 25.)

PLATE II

FIG. 1.—Note the orientation of the prismatic felspar grains and the projection of a quartz phenocryst (left) and biotite (right) across the vein. To the left of the quartz phenocryst the vein splits into three branches. (Polarized light, × 40.)

FIG. 2.—The same vein as in Fig. 1, to the right of the biotite phenocryst and showing an intersection with a large kaolinized felspar crystal (in the right-hand third of the photograph). Note the continuation of the kaolinization across the vein at one point; all the felspar in the phenocryst area is optically continuous. (× 40.)

FIG. 3.—A quartz veinlet (a continuation of Pl. I, fig. 2) intersecting a quartz phenocryst. The shear zone in the latter has not disturbed the large altered inclusion. (Polarized light, × 15.)

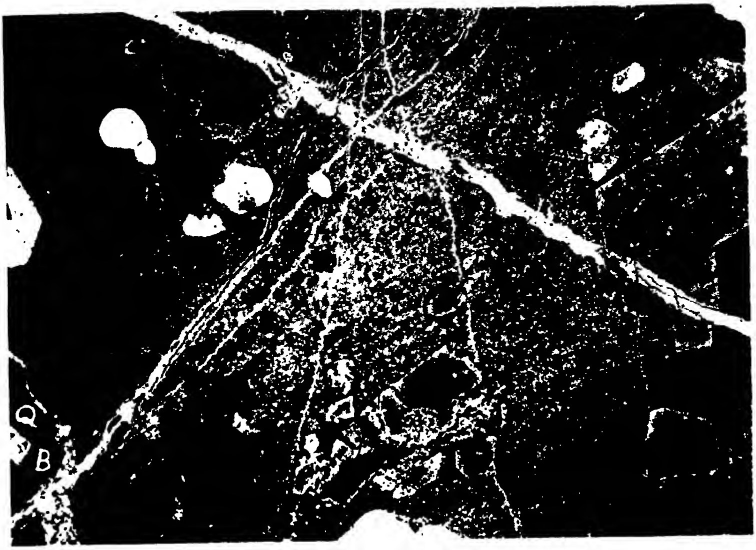


FIG. 1

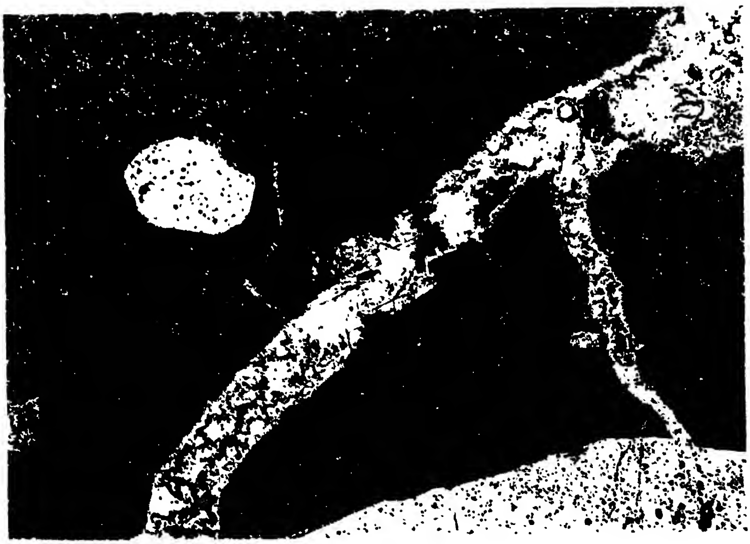
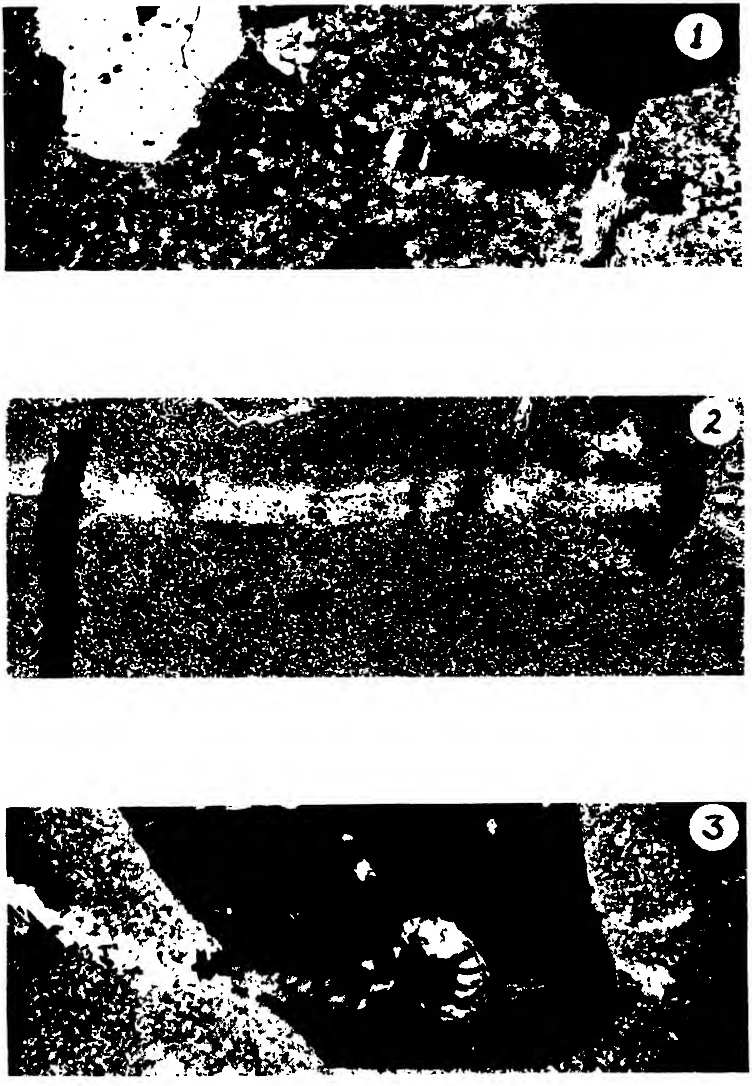


FIG. 2

MICRO-VEINLETS IN CORNISH GRANITE-PORPHYRY.



MICRO-VEINLETS IN CORNISH GRANITE-PORPHYRY.

Revival of Major Faulting in New Zealand

By C. A. Cotton (Victoria University College, Wellington)

Introduction and Advance Summary

AMONG the many faults in the Marlborough district of the South Island of New Zealand four, the Wairau, Awatere, Clarence, and Kaikoura faults, are of the first importance as boundaries between great elongated tectonic blocks that determine the high mountain ranges of this north-eastern corner of the South Island and the basins, or valleys, that guide the principal rivers draining it (Text-fig. 1). Modification of these major landscape features by erosion has proceeded very far, continuing, apparently, for a long time after the differential earth movements that initiated them had come to an end ; but quite recently there has been a general renewal of movement on the ancient lines of dislocation, in some important cases with reversal of the sense of the earlier displacement.

Were such reversed movement to proceed far it would profoundly alter the configuration of the landscape and the drainage pattern. In this district it has just begun ; but in some other New Zealand districts great changes have probably been effected in this manner.

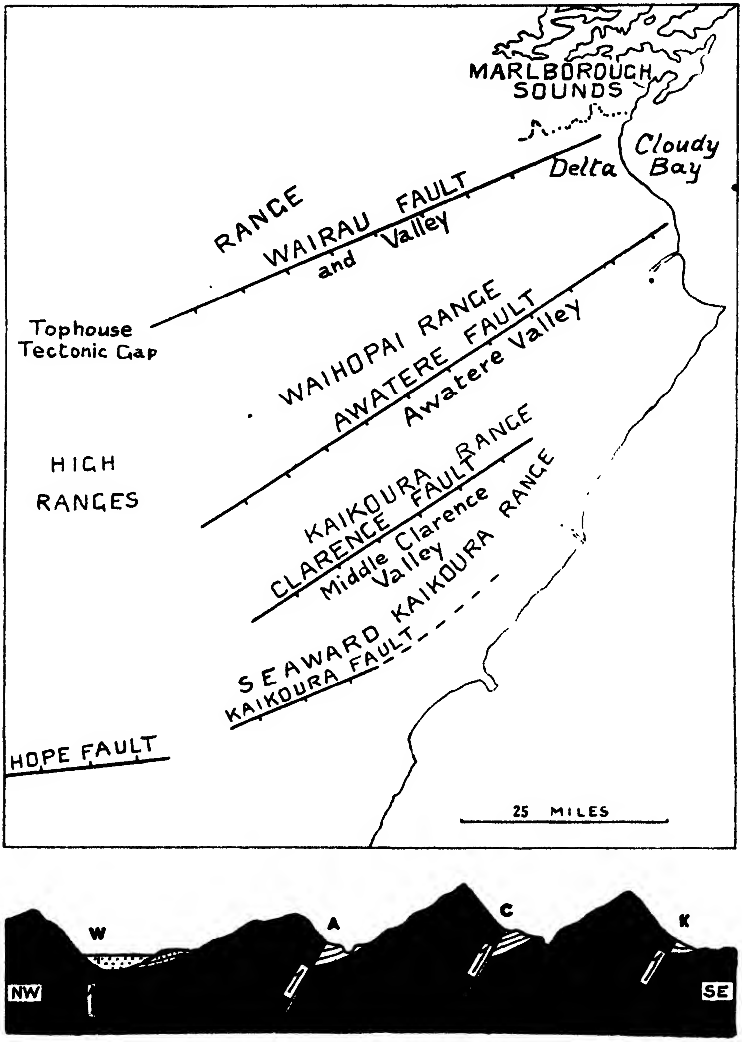
The use of the term " earthquake rent " to describe features produced by recent renewal of faulting is discussed. It seems better to refer to these as rejuvenating and reversed (or " in reverse ") scarplets ; and these may be grouped together as fault " cicatrices ". Some examples of cicatrices with scarplets in reverse are described.

Recent Renewal of Faulting in Marlborough

Since McKay's first account of the geology of Marlborough (7) was published it has been known that this district is traversed by numerous surface traces of faults. These are not merely being revealed by erosion at the boundaries between contrasting geological formations that are in juxtaposition : they are developing as a result of intermittent movement now in progress along faults that outcrop, or actively break the surface. The lines of these faults may be followed for remarkably long distances with no other guidance than the details of the surface form. Their continuity proves that the underlying faults are major features in the structural and tectonic pattern ; they are definitely not an irregular network of short faults such as may be produced by shallow gravity faulting.

The observations of Mr. Allan Prichard, of the New Zealand Public Works Department, a keen observer of landscape details from the air, who has studied very closely the fault outcrops in the north-eastern part of the South Island, and who has described them orally to the writer, confirm the belief that continuity of major faults in this district

is a fact; for he has found that the cicatrices of numerous dislocations that intersect the surface, including some that have not yet been



Text-fig. 1.—Locality map and generalized section showing the major faults and tectonic features of the north-eastern part of the South Island of New Zealand. Faults: A, Awatere; C, Clarence; K, Kaikoura; W, Wairau.

mapped, can readily be followed long distances by observation from an aircraft. Along with other parallel and bifurcating lines he has,

rather surprisingly, observed one along the length of the back slope of the great north-easterly-trending block that forms the Kaikoura Range. From the sinuous line traced across spurs and valleys of this maturely dissected slope (towards the north-west) he concludes that the underlying fault dips north-westward in common with the known major thrust faults that bound the large earth blocks (Text-fig. 1). The fault may be a recently developed branch from the Clarence fault, which bounds the range on the south-east side.

Late Tertiary Orogeny and Erosion in Marlborough

It is of interest to inquire how long the late Tertiary orogenic paroxysm continued in this district. That movements on a large scale began early is known from the presence at the top of the Cretaceous-Tertiary sequence, which in the Kaikoura ranges is involved in the structure, of coarse conglomerates of fluvial and torrential origin which McKay, more or less correctly, described as post-Miocene, and which may have been formed early in the Pliocene period. In the adjacent Nelson and Wairau districts there are vast gravel deposits (Moutere gravels, etc.) of later date which point to continuance or recurrence there of earth movements and consequently accelerated erosion in the later Pliocene and probably also in the Pleistocene (1), but absence of such gravels from the wide tectonic depressions adjacent to the Kaikoura Mountains may be significant. Here there may have been a cessation of faulting and all strongly differential movement for quite a long period. The fact that a number of great faults are now active again does not indicate that there has been a continuance of orogenic movements throughout the late Pliocene and Pleistocene, for the geomorphic evidence in both the Clarence and Awatere tectonic depressions points definitely to a period of rest during which the great south-east-facing scarps of the Clarence and Awatere faults assumed their smooth and well-worn-back appearance. It was during this interval that the Kaikoura Range, by that time stripped of a vast thickness of Cretaceous and Tertiary covering strata, became maturely dissected.

Revival of Orogenic Activity

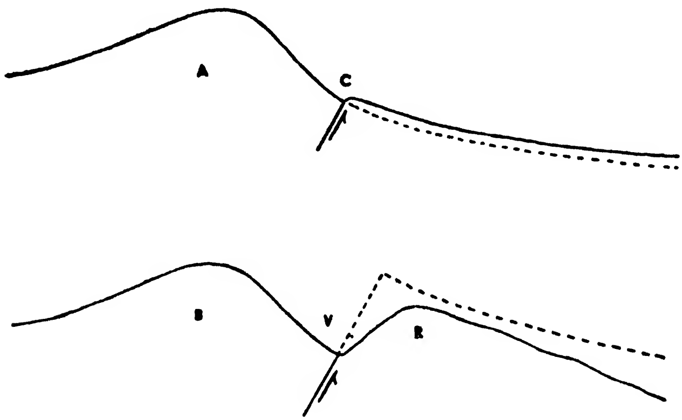
Later, apparently in very recent times, fault movement began again. Unique [1] reverse scarplets that are now conspicuous along the bases of the ranges close to the well-worn ancient scarps then made their appearance. If, as seems highly probable, these have been formed by renewal of fault movement in a reversed sense on or close to old fault lines after long inactivity, it is obvious that such movement has

[1] "Unique" in the sense that nothing of the kind has been observed outside New Zealand.

just begun. If it were to continue, or had it been long in progress, there would be not merely " earthquake rents ", or reverse scarplets, along the range fronts (C, in Text-fig. 2A), but new ranges would arise (R, in Text-fig. 2B) as a result.

Application of the Hypothesis of Faulting in Reverse to the Hope Fault

In some other districts adjacent to Marlborough it is possible—probable indeed—that new ranges have originated in the manner

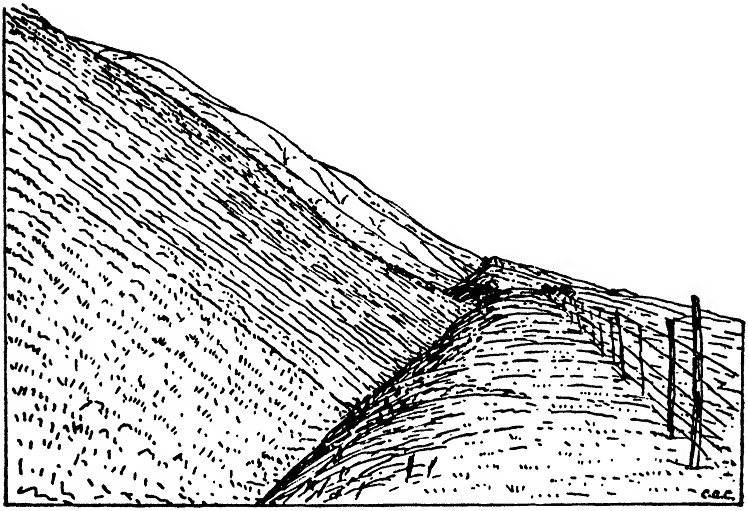


Text-fig. 2.—Effects of incipient movement (A) and continuance of such movement (B), reversing earlier movement at the base of a fault scarp or fault-line scarp. A true fault valley (V) is formed between the ancient scarp (left) and the scarp of the range R, which is now rising.

just indicated. Some valleys that are definitely fault valleys (unless they are fault-line valleys, which is improbable), but have ranges of about equal height on each side, are perhaps best explained by uprise of fault scarps first on one side and then on the other as shown in Text-fig. 2B. An example of such a valley is that followed by the Hope River along the Hope fault (Text-fig. 1). The direction of downthrow on the Hope fault is opposite to that on the Kaikoura fault, of which it has been regarded as a continuation by McKay (8), Park (9), and Henderson (5). If these faults are really one, it may be the case that reversal has taken place at the western end of the line. Perhaps the adjoining country north of the fault line was upheaved contemporaneously with the rise of the Seaward Kaikoura Range. A movement in the reverse direction, still in progress, has, however, lowered and is now lowering the floor of an intermont basin, the Hanmer

Plain, on the *north* side of the fault; and this is accompanied by uplift that is making unilateral river terraces on the south banks of rivers that follow the Hope fault for some distance. It seems probable that these latter movements began comparatively recently.

Perhaps renewed movement on great faults after a long period of rest and erosion may be expected to be in reverse and to develop



TEXT-FIG. 3.—Trench-form fault cicatrice along facets of a composite fault scarp that forms the eastern front of the Ruahine Range, New Zealand. In addition to this new break on the line of an old major fault (reversing its downthrow) there is another, of similar form though not so deep, higher up on the facets of the scarp.
(*Drawn from a photograph taken by R. J. Waghorn.*)

large displacement, at least in some cases, for the cause of movement may no longer be compression, as it was when the Awatere, Clarence, and Kaikoura thrust faults (Text-fig. 1) were initiated, but rather some response to a need for isostatic adjustment, in which case faulting may follow old planes of thrust dislocation or develop close to these, but gravitational adjustment accompanied by normal faulting may now be the rule.

USE OF THE TERM "EARTHQUAKE RENT"

McKay apparently found the term "earthquake rent" already in use in Marlborough, and adopted it as it was there employed for two distinct kinds of feature, both of which, being related to the outcrops of faults, may occur together. These are: (*a*) "What either is or has

been an open fissure " (8), i.e. a crack, cracks, or a system of related cracks in the ground of a kind commonly opened during earthquakes, which may extend to no great depth and are soon obliterated ; and (*b*) continuous trenches along mountain-sides which McKay apparently found difficulty in describing, but has referred to as " a sudden drop, producing a kind of sunken wall, which . . . can sometimes be traced to great distances " (8). He seems to have been content to class these together and has confused them in his descriptions, as the Marlborough settlers did, because of the belief that they originated in the same way, i.e. by gaping of the fault fissure and not because of differential movement on the walls of the fault.

Believing that the use of the term " earthquake rent ", which, moreover, has come to have no definite meaning, might imply continued adherence to the gaping-fault theory of origin, to which he at one time gave serious consideration (2), the writer has abandoned its use and had more recently (3) referred to trench-form fault and earthquake traces as " reverse " scarplets, for there can be no question of the origin of these as a result of reversal of fault movement. Together with rejuvenating fault scarplets,[1] which afford evidence of renewal of fault movement in the original sense, these may be classed as surface traces, or *cicatrices*, of faults.

McKay's accounts of the features that mark the outcrops of the great Awatere and Clarence faults are obscure, perhaps because he was influenced by the gaping-fissure theory of origin ; and it is obvious that Hector (4), when he summarized and commented on McKay's report, had misunderstood his cryptic accounts, for Hector has given his readers the impression that the features referred to are simply rejuvenating scarplets at the bases of more ancient scarps or fault-line scarps, as the case may be. It appears that when McKay later saw and understood the significance of rejuvenating scarplets along part of the Kaikoura fault and in the Wairarapa district of the North Island he classed these also indiscriminately in the category of " rents ", too greatly extending the meaning of this term and contributing to the confusion.

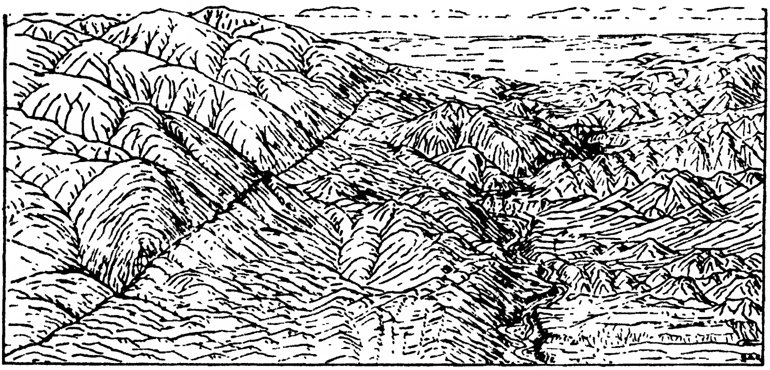
Reverse Scarplets

Part of the reverse scarplet along the outcrop of the Clarence fault, an excellent example of the form that was reported in the first place by McKay (7), was described by the writer (2) as taking " the form of a bench about 20 feet in width following an approximately straight line up and down over the smaller inequalities of the surface along the facets of the front scarp of the range ". An accompanying sketch

[1] " Scarplet " has been used by E. Blackwelder, who attributes it to W. M. Davis.

showed that the feature was for a considerable distance trench-like rather than bench-like. It was pointed out that evidence was lacking of strike-slip movement such as would be afforded by short scarps facing in opposite directions on opposite sides of transected spurs.

The trench form was observed, photographed, and sketched by Waghorn (10) also, who described " rents " along the east front of the Ruahine Range, in the North Island. There are two of these cicatrices across the facets of a composite fault scarp and another several miles away on another fault. The two on the Ruahine scarp



TEXT-FIG. 4.—View from the air (from a photograph) looking north-east down the Awatere tectonic valley and showing the cicatrice of the Awatere fault along a composite fault scarp (at left).

are parallel to each other (in plan) and touch contours that are 500 feet apart vertically. The scarplets face the main scarp, making trenches (Text-fig. 3) ; and Waghorn has commented on the fact that the recent movement has reversed that which took place when the range was upheaved. The displacement, or depth of the trench, is 20 feet in the case of the lower cicatrice, which is on a line of major faulting. From this the second fault is perhaps a branch. It is possible, according to Waghorn, that as much as 2 feet of the displacement occurred at the time of the Hawke's Bay earthquake of 1866.

The most conspicuous and certainly the longest and most continuous of known cicatrices with the trench form is the one that was first known and described as an " earthquake rent ". It follows the north-western wall of the Awatere Valley—the line of the Awatere fault—and can be traced continuously for at least 60 miles (Text-fig. 4). In places the trench in the case of this example is swampy and holds standing water after rain. Ponds so formed are not at all closely analogous with Californian " sag ponds ", however, which are

developed by the wrench along a strike-slip fault ; in this case, as in the case of the Clarence example, there is no evidence of any appreciable lateral movement.

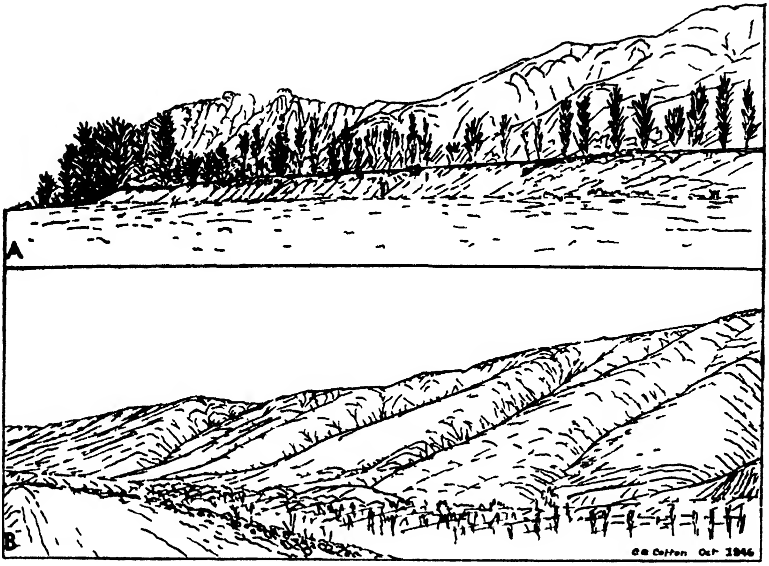
As noted earlier, the descriptions of this feature given by McKay and Hector are misleading and fail to convey any idea of the surface form or the nature of the movement that has made it. So also does that supplied by Sir Frederick Weld to Lyell (6) and incorporated in the tenth edition of the *Principles of Geology*. The fact that cracks developed along the fault trace during an earthquake in 1848 led to a local belief that the whole feature originated at that time, but this cannot have been the case. If there was any differential movement on the fault in 1848 it was not reported, but it is quite possible that in the excitement of viewing " rents " 18 inches wide observers failed to note evidence of displacement.

Rejuvenating Scarplet of the Wairau Fault

In contrast with the cicatrices already described there is one on the line of the Wairau fault (one of the major lines of dislocation in Marlborough shown in Text-fig. 1) that shows rejuvenation, or renewal of movement in the former sense, on this fault. The Wairau Valley from the Tophouse tectonic gap in the ranges of the main divide of the South Island to the sea at Cloudy Bay is a large tectonic depression, the late geological history of which is probably less simple than that of those flanking the Kaikoura Range, for it contains very young gravel formations thousands of feet thick which not only must have accumulated during or immediately after great earth movements, but are also themselves somewhat disturbed (1). Here again, however, there has been a very belated renewal of faulting on the line of the Wairau fault, for a scarplet rejuvenates the fault (or has been formed on a line closely parallel to it) and extends continuously from end to end of the depression. The writer is indebted to Mr. Allan Prichard for showing him from the air this astonishingly continuous rectilinear feature. Midway up the valley, where the scarp is parallel to the West Coast highway and is easily accessible for several miles, it is uniformly 8 feet high and breaks the level surface of a gravel terrace near the middle of the wide valley (Text-fig. 5A). Its downthrow is to the south-south-east, which is here the direction away from the Wairau River. Small tributary streams have been ponded to make a swampy tract that extends for several miles.

In places this cicatrice, as Branch and Dagger (1) have observed, dislocates the margin of an extensive deposit of high-level alluvial gravels that forms the south side of the valley for many miles. The extent of the displacement seems here to be greater than where measured at the locality already mentioned, and the feature assumes a re-entrant,

or V-notch, form that has been described as a "rent". The reason for this form is, however, merely that the general slope of the ground surface dislocated is northward, towards the Wairau River, whereas the scarplet faces southward. The trace of the fault traverses also the alluvial plain of the lower valley of the Wairau and crosses the terraces of alluvium already mentioned, which are very young It is



TEXT-FIG 5—Views looking west along the northern wall of the Wairau Valley tectonic depression

A In the foreground is a rejuvenating scarplet, 8 feet high, on or parallel to the line of the Wairau fault

B Near Tophouse, at the western end, the wall becomes a straight and well-preserved fault scarp 4,000 feet high

probable that all these alluvial deposits have accumulated either over a fault scarp or over the river-planed outcrop of the fault which the scarplet rejuvenates.

At first sight it is puzzling to find this scarplet not only out in the middle of the alluvium-filled valley (Text-fig 1), but also facing away from the depressed and in part deeply submerged Marlborough Sounds block of country Reversal of the sense of fault movement is not indicated by this, however, for west-south-westward the Sounds block loses the characteristics of a depressed and drowned landscape and becomes a high range that presents a well defined, straight, and little dissected fault scarp towards the Wairau Valley (Text-fig. 5B.) The valley-floor scarplet joins this near the Tophouse gap and becomes

clearly a scarplet of rejuvenation at its base. The movement of tilting or warping of a large block of country that has drowned the margin of the Sounds district has quite probably not been associated with movement on this fault, which, with downthrow towards the Wairau Valley, bounds a large positive tectonic element of the structure.

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Some Superficial Structures in the Cornbrash of Northamptonshire

By J. E. PRENTICE and P. A. SABINE [1]

1. INTRODUCTION

THE area to which this paper refers comprises that part of north Northamptonshire and Huntingdonshire lying to the east of the River Nene, not far from Oundle, 10 miles W.S.W. of Peterborough. It lies immediately east of the Northampton Ironstone Field, and is largely included in New Series, Sheet 171, and the adjacent parts of Sheets 157, 158, and 172 of the Geological Survey. The area was originally surveyed on the 1-inch scale by Judd (1875), and maps and memoirs published in 1872–6. Apart from the description of certain sections, notably by Beeby Thompson (1928, 1930) and Douglas and Arkell (1932), no subsequent work was done in this area until the Geological Survey commenced the primary 6-inch survey in 1939. During the progress of this work Survey Officers observed many structures which, by their relation to topography, were deduced to be of superficial origin. Hollingworth, Taylor, and Kellaway (1944, 1946) have given us a key to the interpretation of many puzzling features of structure and topography in the Jurassic scarplands, and it is their pioneer work which has made the present paper possible. In the area east of the Nene many of the types of structure described by those authors can be observed; there are, in addition, other structures which appear to be of similar origin, and which it is now desired to place on record.

2. OUTLINE OF THE GENERAL GEOLOGY AND PHYSIOGRAPHY

The River Nene flows in a broad valley to form the western boundary of the area mapped by the authors; the ground rises to the east in a series of steps and shelves to a broad tableland at a height of some 260 feet O.D., or 200 feet above the level of the river. This tableland, which is composed of Boulder Clay resting on Oxford Clay, will be referred to as the Boulder Clay Plateau. The base of the Boulder Clay maintains a general level of 180 to 190 feet O.D., and below this all beds from the Oxford Clay to the Upper Lias crop out. Text-fig. 3 gives an idealized horizontal section across the country from west to east.

The rocks which outcrop within the area consist of an alternating series of clays and limestones lying between the thick Lias clays below and the Oxford Clay above, and thus give a succession of inter-

[1] Published by permission of the Director, Geological Survey and Museum.

bedded competent and incompetent strata particularly suitable for the development of superficial structures.

The generalized succession is as follows :—

		Feet.
	Boulder Clay	Up to 80
Oxford Clay (s.l.)	Oxford Clay	40–100
	Kellaways Sand	6– 10
	Kellaways Clay	6– 10
	Cornbrash	5– 10
Great Oolite Series	Great Oolite Clay	9– 16
	Great Oolite Limestone	13– 20
	Upper Estuarine Series	35– 40
Inferior Oolite Series	Lincolnshire Limestone	0– 10
	Lower Estuarine Series	20– 25
	Northampton Sand	Very thin or absent
	Upper Lias Clay	150–180 ft. (10 ft. seen)

Over most of its course the River Nene has cut down into the Upper Lias Clay, and the slope above the river is formed of the sands, silts, and clays of the Upper and Lower Estuarine Series, capped by the Great Oolite Limestone which forms a distinct scarp overlooking the river (see Text-fig. 3). Above this escarpment is the gentler slope formed by the variegated clays comprising the Great Oolite Clay leading up to the small scarp formed by the edge of the extensive Cornbrash outcrop. This bed, which here concerns us most, is succeeded by the Kellaways Beds and the Oxford Clay, overlain in turn by the Boulder Clay. The beds have an exceedingly gentle dip to the east, of the order of 1 in 250 : to all intents and purposes, therefore, the beds may be regarded as horizontal.

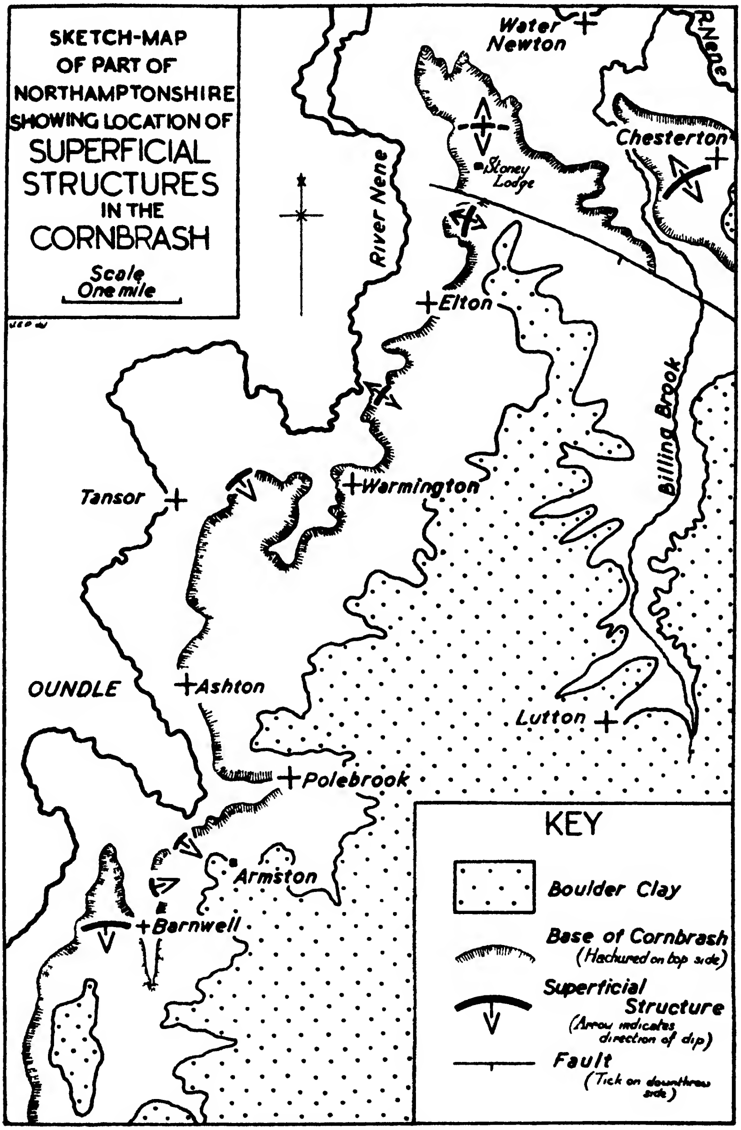
The Cornbrash, though only 10 feet in thickness at its maximum, is a hard compact limestone which is peculiarly resistant to erosion, and forms a broad flat platform, usually five or six hundred yards wide, but in places stretching for as much as two miles. The nearly horizontal position of the strata, associated with the resistant nature of the Cornbrash, results in the feature formed by that bed nearly following the contours, and any deviations from normal structure is instantly apparent.

The deep-seated tectonics of the area are quite simple, consisting of shallow folds and faults with a general N.W.–S.E. trend. One fault lies between Elton and Chesterton and is shown on the sketch-map (Text-fig. 1). Shallow folds of similar trend affect the Cornbrash and other outcrops between Elton and Ashton.

3. Method of Investigation

Exposures in this area are rare and the elucidation of the geology has been almost entirely performed by the regular and constant use of a 5-ft. hand-auger. In each investigation, the abnormality of

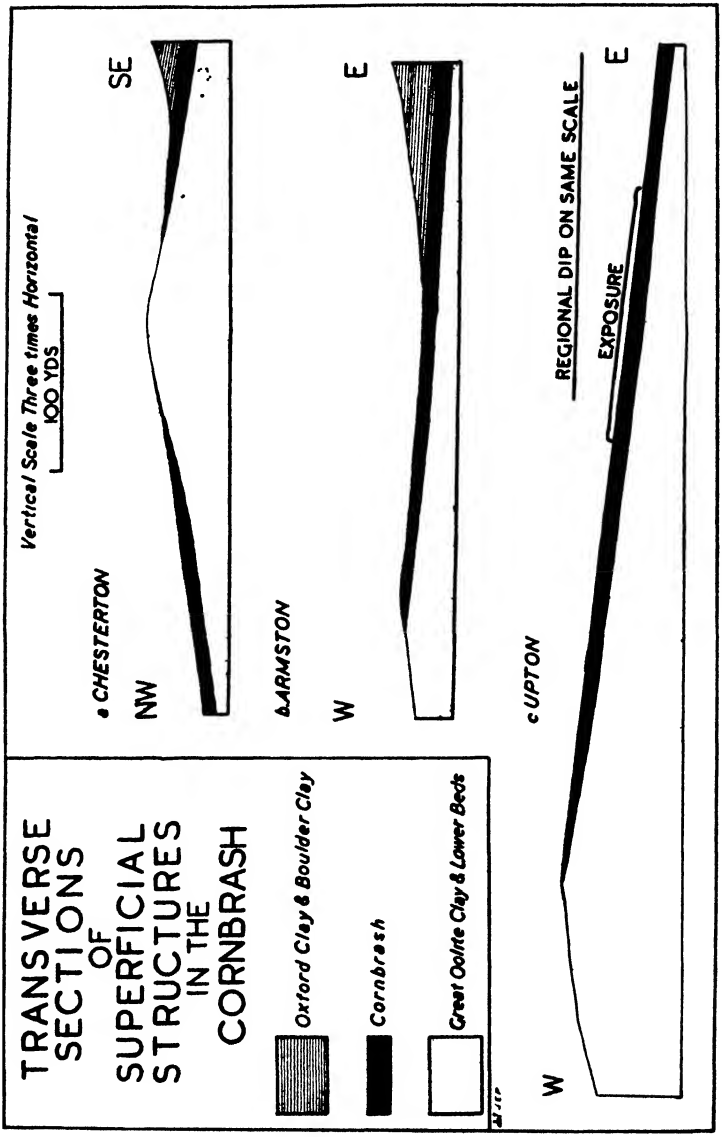
structure was detected from the topography; the boundaries were carefully traced by augering, and a traverse made with an Abney



TEXT-FIG. 1.

level across a typical portion of the structure. Sections were then drawn from this data, three of which are shown in Text-fig. 2. In

the construction of these sections every possible attempt was made to account for them in an orthodox fashion. The sections therefore



TEXT-FIG. 2.

represent the minimum deviation allowed by the available data from the horizontal disposition normal in this area.

Augering as a method of geological mapping is entirely satisfactory in this area, as with a little experience the various clay formations can readily be distinguished from one another.

4. The Superficial Structures

When certain portions of the Cornbrash are examined in detail it is found that in some areas the dip is greater than the regional dip, a crest consequently being formed within the Cornbrash platform.

The examples described below fall into two categories, distinguished by the position of the highest part of the Cornbrash in relation to the platform as a whole. The first type shows itself as a distinct crest or ridge within the platform itself, in the form of a small anticlinal structure, parallel to the trend of the outcrops, and dying away in both directions along its axis. Into this group fall structures at Chesterton and at Stoney Lodge, Elton. The second category, in which the crest coincides with the edge of the Cornbrash platform, is seen only as an increase in the slope of that platform, over and above that produced by the regional dip. Nevertheless, there is an essential similarity between all the structures which suggests that they have arisen from the same fundamental causes.

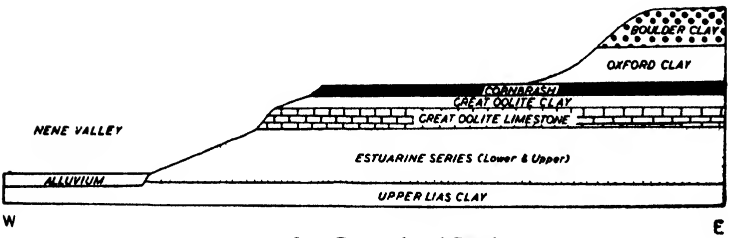
The most striking example in the area is that which is situated west of Chesterton village, on the north side of the main road. A broad platform of Cornbrash stretches to the north-west for a distance of one mile, beyond which the ground falls to the Nene alluvium. The platform is bounded on the west by the small valley of the Billing Brook, and on the east by a second small valley ; both of these drain northward to the Nene. Immediately to the north of the main Oundle–Peterborough road is a very distinct crescentic ridge, oriented mainly east–west, in marked contrast to the level stretch of Cornbrash to the north. The ridge is some 400 yards long, 300 yards wide, and 30 feet high ; to the east it gradually dies away, and to the west the crest turns southwards to die out in the valley of the Billing Brook. Lying along the crest of the hill the Great Oolite Clay is found in boat-shaped outcrops, and a typical cross-section constructed by the methods described above is shown in Text-fig. 2 (*a*). It is evident that, in plan, the axis of the ridge closely follows the curve of the base of the main mass of the Oxford Clay, and this is regarded as a significant fact in the consideration of the origin of the structures.

Two miles west-south-west of Chesterton, at a point a quarter of a mile south of Stoney Lodge, Elton, the Cornbrash " flat " is broken by a narrow ridge, some 150 yards from, and parallel to, the base of the Oxford Clay. This ridge is smaller than the Chesterton structure, and no clay is exposed in its axis ; like the latter it dies out laterally. A contoured plan of the Cornbrash " flat ", a mile south-west of

Water Newton, made before artificial levelling was carried out, reveals that similar structures existed in this area, and in each case their orientation was parallel to the sides of the valley.

Just south of Elton Park the Cornbrash is affected by a similar structure, but river gravel obscures the boundaries and gentle east-west flexures complicate the structures, so that the precise details are uncertain.

The simpler type of structure, revealed solely as an increase in the amount of slope on the Cornbrash platform, is shown in section in Text-fig. 2 (*b* and *c*). A typical example is at Armston, south-east of



TEXT-FIG. 3.—Generalized Section.

Oundle. Armston Farm is situated on the top of a hill capped by a lobe of boulder clay, overlooking the valley of the Nene. Below the boulder clay, a steep slope of Oxford Clay falls away, and Kellaways Beds feather out on to the Cornbrash platform, which extends for about 600 yards towards the river. Instead of lying flat, however, the Cornbrash rises at a gradient of 1 in 30 from the base of the Kellaways Beds, finally forming a distinct ridge, over which the main road runs. Although the slope corresponds in direction with the regional dip, it is evident that the gradient is far too steep to be accounted for by this alone. The structure cannot be traced far in either direction, nearby outcrops aligned with it being unaffected. From the summit of the ridge the ground falls rapidly towards the river. In all probability the Cornbrash is cambered to a certain extent down the face of the slope, but a downwash of fragments of Cornbrash obscures the actual base of this formation.

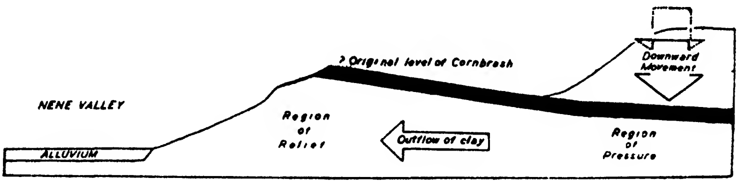
About a quarter of a mile to the south-south-west, in the area immediately to the north of Barnwell Castle, a similar phenomenon can be observed, the level of the Cornbrash-Kellaways Beds boundary being some 10 feet below the valleyward edge of the Cornbrash platform. Even if the full thickness of the Cornbrash is present at the edge of the platform, this involves a fall of 10 feet in 200 yards, a dip of 1 in 60. The boundaries of the formations have here been accurately

determined from the evidence provided by a line of post-holes traversing the succession.

There is some evidence from Ordnance Survey bench-marks and spot-heights, that the long spur which lies between the valley of the Nene and that of the Barnwell Brook (which flows through Barnwell) has been affected by similar movements, the whole of this mile-long platform being gently tilted in a southerly direction.

Half a mile east-north-east of Tansor, another instance of the steepening of slope of the Cornbrash platform by superficial movement can be observed, but in this case a mantle of river gravel prevents satisfactory elucidation of the structure.

The largest example examined of this type of structure lies north-



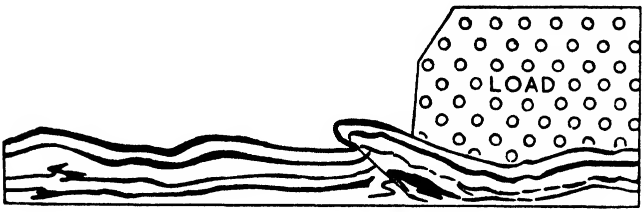
TEXT-FIG. 4.—Diagram to illustrate mode of origin of "Armston" type of superficial structure.

east of Wansford, near the village of Upton, north of the area shown in Text-fig. 1. Text-fig. 2 (*c*) gives a west-east section of this structure. Here the Cornbrash is exposed in a long dip section and the bedding plane between two contrasted lithological types of Cornbrash shows clearly the accentuated dip, which is of the order of 1 in 25. On the scarp face below the Cornbrash platform the normal thickness of Great Oolite Clay seems to be present. The Boulder Clay Plateau lies half a mile away to the north-east.

5. Interpretation of the Structures

That these structures are of superficial, and not of deep-seated, origin is evidenced by the fact that they bear no relation to the known tectonics of the area, either in direction or form. Although both deep-seated faulting and folding are present, the relationships of the small-scale structures are entirely with the topography, and they closely follow the form of the outcrops and the trend of the Nene valley. They are, moreover, of limited size and extent, usually dying away laterally; and are unconnected with one another. The work of Hollingworth, Taylor, and Kellaway in the Northampton Ironstone Field has revealed that in every case the structures they describe can be attributed to the plastic condition of certain of the Jurassic beds. The main flow under load has taken place in the thick clays of the

Upper Lias, which underlie the whole of that region and which form the floors of the major valleys. In the area described by those authors the cause of the movements was adduced to be the weight of alternating beds of limestone and clay, which themselves suffered deformation as a result. In the area at present under description a thin limestone overlies a succession of clays and limestones; but the main cause of the movement is not the inherent weight of these sediments, but rather the additional weight of the large mass of Oxford Clay and Boulder Clay which overlies them in the region distant from the valley. This gives rise to a condition of unequal loading and strains are therefore set up within the underlying strata. The probable effect



TEXT-FIG. 5.—Modified from Rettger (1935). Diagram showing deformation due to differential loading.

is shown in Text-fig. 4. The valley and the area of Lias-Cornbrash outcrop are regions where the pressure resulting from the load of Oxford Clay and Boulder Clay can find relief, and the plastic clay formations will flow towards the valley. The result will be a general lowering at the margin of the Boulder Clay Plateau and the consequent tilting of the Cornbrash platform. This is probably the origin of those structures seen at Armston and Barnwell, etc.

The Chesterton structure presents a somewhat different problem, lying as it does well within the Cornbrash platform, and separated from the edge of the outcrop by a mile-long stretch of horizontal Cornbrash. The slope of the side nearer the Boulder Clay Plateau may be regarded as analogous to that of the Armston and Barnwell types. The other limb of this small " anticline " is more difficult to interpret. It seems unlikely that downward movement of the Cornbrash platform on the valleyward side of the structure would have affected the platform in such a way that the majority of it remained perfectly horizontal and only a small upstanding ridge was left to mark its original level. The other alternative is the postulation of a certain amount of upward movement in the limited area of the ridge. The following suggestion is offered as a probable mode of origin. The distance from the structure to the outcrop of the underlying clays is considerable, and neither of the two subsidiary valleys cut down to any considerable depth. The

outflow of clay from beneath the Boulder Clay Plateau would be restricted by the large amount of clay between it and the valley. Probably the force would not be sufficient to work against the friction of bed on bed over such a great distance, and relief of pressure would be more easily achieved by a buckling of the strata in front of the Boulder Clay Plateau.

This hypothesis gains support from some experiments performed by Rettger (1935) on the loading of layers of sand and clay. Text-fig. 5 summarizes his results upon loading one end of an even spread of layers of clay and sand. The sharp folding immediately in front of the load is shown very distinctly and corresponds in position to the Chesterton structure. There is also similarity to the mud lumps at the mouth of the Mississippi, described by Shaw (1913). Here the weight of accumulated sediments brought down by the river is deduced to be the cause of bulging-up of the underlying mud, in the form of a " mud-lump ".

The present state of our knowledge of the deformation of soft sediments in bulk is, however, so limited that any hypothesis of this sort can be only tentative. The flat-lying nature of the beds, the lack of exposures, and the mantle of drift are all factors which operate against completely satisfactory elucidation of many interesting features in this area. The authors feel, however, that the importance of superficial structures in areas of flat-lying beds is very great, and present these results as a further illustration of this fact.

The authors' best thanks are due to Dr. J. H. Taylor for his valued advice and criticism both in the field and in subsequent discussion ; and to him and Professor S. E. Hollingworth for reading the manuscript and offering many helpful comments and suggestions.

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Synthetic Quartz Crystals.

By G. Van Praagh

WAR-TIME requirements for untwinned quartz focused attention on the laboratory production of quartz crystals. Both the Germans and ourselves devoted considerable effort to this project with the result that, by the end of the German war, both countries were in a position to begin large scale manufacture. The fact that quartz crystals can be grown from aqueous solution in a short time is of considerable significance for geologists, and the method will therefore be described in some detail.

In 1904 Spezia succeeded in depositing quartz from aqueous solution on to a seed crystal of quartz which was thereby increased in size by about 20 per cent. The specimen is in the Geological Museum at Oxford. The first attempts at growing quartz crystals in this country during the war were based on Spezia's method. The seed crystals were suspended in a high pressure system containing dilute sodium silicate solution which circulated over a quartz source maintained at a higher temperature than the seed chamber. Studies of the solubilities of the various forms of silica in aqueous solvents containing a wide range of alkaline solutes led to the adoption by both the Germans and ourselves of an isothermal method. It was found that vitreous silica is about ten times as soluble as alpha quartz in the neighbourhood of the critical temperature of water, thus by heating vitreous silica to that temperature in the presence of a suitable aqueous solvent and a quartz seed crystal, transference of the silica to the quartz seed might be expected. This was found to occur, but there is as yet no theory to explain how the silica is transported through the water, which, at the critical point, is in the vapour, rather than the liquid state. The British work is briefly described in a letter to *Nature*, 157, p. 297 (1946). The following is a description of the German work, carried out by Professor R. Nacken of the Mineralogical Institute, Frankfurt University.

Nacken had been working on the growth of crystals of various kinds since 1912 and has since worked on the synthesis of several minerals including quartz, using a hydrothermal method in the neighbourhood of the critical temperature of water. For this purpose high pressure vessels were constructed and many hundreds of experiments carried out in which temperature, the nature of the solvent and concentrations were varied.

As a starting point for the production of quartz crystals, seeds in the form of thin lamellae were used. These were cut from the rhombohedral face of a natural quartz crystal. Under favourable conditions rapid growth occurred so that, for example, a rhomb 1·5 cm. in length

and 2–3 mm. thick was obtained in 4–5 days. If the original seed was untwinned, the crystal grown was also untwinned. The raw material consisted of chemically pure vitreous silica, about 3–5 gm. being used in an autoclave of 30 ml. capacity. The autoclaves were made of steel and comprised an inner cylindrical vessel of about 25–30 ml. capacity lined with silver and contained in an outer vessel with thick walls closed by an internal screw plug. This plug also served to support the seed crystal, which was suspended from a silver filament. The solvent occupied about 20 per cent of the capacity of the vessel when at room temperature. The temperature was raised to about 370–400° C and maintained at this value for the duration of the experiments, namely several days. Under these conditions, the water is at the critical point and completely fills the vessel, the pressure being about 400 atmospheres. A great variety of alkaline aqueous solvents were used ; the most suitable were solutions of sodium bicarbonate of concentrations N/10, N/100, and N/1000. The use of stronger solutions brought about quicker growth but was attended by several disadvantages ; more unwanted nuclei formed and grew on the walls of the vessel, and the synthetic crystal contained occlusions of impurities. The use of weaker solutions produced better growth and clearer crystals, but the rate of growth was lower. A compromise had to be found and a concentration of N/1000 was usually the most practicable.

Variation of the experiments showed that many sets of conditions produced successful results, from which the best could be selected. There was always the chance that the silica would deposit on the walls of the autoclave. This might occur in a few hours and rapidly give rise to a thick layer which would obstruct the growth of the seed crystal. By the choice of suitable experimental conditions and by the addition of such substances as sodium oleate, gelatine, stearin, etc., the formation of unwanted nuclei could be minimized without compromising the speed of growth of the seed crystal.

As stated above, a crystal about 1·5 cm. by 0·3 cm. could be grown from a thin plate about 0·5 mm. thick in the space of a few days. The rate of growth depends on the direction of growth, and the shape of the final crystal can be influenced by additions to the solution. The basal surface of quartz is never observed, it must therefore grow very quickly compared with the rhombohedral surfaces and finally degenerate into the pointed terminations of the crystal. The prism surfaces usually have a lower rate of growth than the rhombohedral ; the trigonal faces grow faster and therefore remain small or disappear. R- and L-quartz behave the same as regards rates of growth. In one experiment, a sphere was cut from a natural quartz crystal and allowed to grow. Along the c-axis growth was rapid and rhombohedral surfaces formed at both ends. Towards the equator a number of

contiguous rhombohedral surfaces formed, lending a barrel-like appearance to the crystal. The final crystal was of the form of a hexagonal bi-pyramid ; prism surfaces develop only after a much longer period of growth. Such tests show that, under these conditions of growth, quartz is deposited in a direction perpendicular to the rhombohedral planes. The original sphere was untwinned, weighed 3·33 gm. and increased in weight by 2·0 gm. in four days. This test also shows the exceptional speed with which silica crystallizes, the biggest difficulty in getting a well-formed, homogeneous deposit being to retard the growth.

Although outside the scope of this article, it is interesting to note that Nacken used with success a similar hydrothermal method for the synthesis of other minerals, including felspars, micas, and beryl. He made large numbers of synthetic emeralds, using a trace of chromium to produce the colour. Hexagonal prisms weighing about 0·2 gm. were grown in a few days. A number have been sent to the Mineral Department of the British Museum for full examination.

In considering the relevance of this work to the geologist, it is pertinent to ask where in the earth's crust the conditions used in the laboratory for the above experiments are to be found. Rough estimates are possible and it appears that a depth of about a mile should be sufficient to give the necessary pressure, i.e. 400 atmospheres, and that at 5 miles depth the temperature might be in the neighbourhood of 370° C. Hence the conditions for rapid hydrothermal growth of quartz and other minerals may exist at no very great depth in the earth's crust, a deduction which should be of considerable significance in connection with theories of petrogenesis.

Steganocrinus westheadi n.sp. and Note on a rare Crinoid and a Blastoid from the Carboniferous Limestone of Coplow Knoll, Clitheroe

By JAMES WRIGHT

(PLATE III.)

THE purpose of this note is to place on record two rare crinoids and a blastoid recently found at Coplow Knoll, Clitheroe. One of the crinoids belongs to a new species of Camerata now named *Steganocrinus westheadi* in honour of its finder, Mr. Stanley Westhead, of Clitheroe. The genus *Steganocrinus* has not hitherto been recorded from English Carboniferous rocks so that its occurrence at Coplow is noteworthy. The other crinoid, here temporarily assigned to "*Pachylocrinus*" *conicus* (Phillips), shows a considerable portion of the arms and was found by the author on a visit to Coplow last year. No other specimen of this species so complete has yet been recorded. On a later visit in the autumn of the same year a single finely preserved specimen of a blastoid was found. In its general characters this specimen does not appear to differ from *Orophocrinus pentangularis* (Miller), and in ordinary circumstances would call for no special comment here. Blastoids, however, are so rare at Coplow that the occurrence of this specimen, the only one ever found by the author at, or known to him from, this locality, is deemed worthy of record.

Steganocrinus westheadi sp. nov.

Pl. III, figs. 4–7

Theca of moderate size ; dorsal cup rather rounded, only faintly lobed ; basal circlet somewhat flat ; RR large ; $PBrBr_1$ much constricted distally, and alone forming part of cup wall ; tegmen low, composed of comparatively few plates, faintly tubercular ; dorsal cup plates ornamented with radiating ridges which coalesce with those on adjoining plates and with tubercles between the ridges.

Holotype.—Stanley Westhead Coll. No. 390.

Locality.—Coplow Knoll, Clitheroe.

Dimensions of Holotype.—Extreme height of theca, over all, including part of anal tube preserved, 33 mm. ; height of dorsal cup to upper limit of PBr_1 anterior side, 19 mm. ; height of dorsal cup to upper limit of PBr_1 on left posterior, 17·5 mm. ; height of tegmen at arm bases, 9 mm. ; width of dorsal cup, post. to ant., 27 mm. ; ditto laterally, 26 mm.

Remarks.—The present specimen consists of a theca somewhat damaged at the arm bases, but otherwise in good condition. Although imperfect there appears to be sufficient evidence to indicate that it belongs to the genus *Steganocrinus*. There are no traces of arms or

arm trunks ; but in the dorsal cup the greatly constricted first primibrachs at their distal ends and the outward flare of these plates, at least two of which have portions of the primaxils attached, together with the general habit of the theca, all suggest reference to this genus. Certainly, in its general characteristics, this specimen is unlike any species of *Actinocrinites* or *Cactocrinus* known from Coplow or elsewhere in England. Kirk (1943) in his recent revision of *Steganocrinus* points out that in this genus the RR and $PBrBr_1$ alone are incorporated in the cup walls proper and this is certainly the case in this Coplow specimen. The dorsal cup is rounded and only shows a slight lobation in the radial series. This would seem to link it more to *Cytidocrinus* than to *Steganocrinus*, but considering the imperfect nature of the theca it seems better to refer it to the latter genus meantime. As to the species, the Coplow specimen bears some resemblance to *Steganocrinus concinnus* (Shumard) as figured by Wachsmuth and Springer (1897, pl. lxi, figs. 5a and 5b), but has less tumid plates and a flatter basal circlet. It also has something in common with *S. pentagonus* (Hall) figured by the same authors (pl. lxi, figs. 3*a*–3*c*), but the Coplow form has a much rounder dorsal cup.

Pachylocrinus conicus (Phillips)
Pl. III, figs. 8–10

Cups with general outlines similar to the cup figured by Phillips as *Poteriocrinus conicus* (1836, pl. iv, fig. 3) are fairly common at Coplow and are represented in various museums. In my own collection are about forty specimens, and from a somewhat cursory examination of all these it appears likely that more than one species is represented. Of course the great difficulty to be encountered in distinguishing the species to which they belong is that none of the aforesaid examples have any part of the arms preserved. The anal area in all is of the primitive three plate plan with RA, anal X and RX well within the cup limits. So far as examination has gone there is no variation from this although there are comparative differences in the size of the anal plates. As a distinguishing character, therefore, the only criterion is the general shape of the cup. From Phillips's figure of *P. conicus* one gathers that the cup is elongated, not greatly expanding at the top, and has high infra-basal circlet with comparatively little taper in an upward direction. Presumably the specimen itself is in the British Museum, but has not so far been examined. In the Yorkshire Museum, at York, however, is a cup which matches the figure of Phillips very well. This cup has prominent IBB and altogether has less taper than the generality of forms usually assigned to the species. Some of the Coplow cups resemble the York specimen, others do not in that they are less high and swell out considerably at the top and

have a more tapering IBB circlet. In the latter category may be placed the specimens figured by myself in 1942 (pl. x, figs. 9, 10, 12). One of these cups, now refigured on Pl. III, figs. 9 and 10, has the lower part of the arms in position all round the radial circlet. This was the first specimen to be recorded showing these structures. The cup in this specimen is slightly deformed, but otherwise well preserved, and the general characters of the arms in their proximal position are excellently displayed. The primibrachs number two in all five radii. A feature to be noted in this specimen is the greater width of the anterior ray, but this may be partly, if not entirely, due to the deformation of the cup at an early stage in the life of the crinoid. As seen from the posterior (Pl. III, fig. 9) the crinoid would seem to have been impelled to the right by current action or otherwise. Specimens of *Actinocrinites* are occasionally found at Coplow showing a similar tendency, but not always in the same direction in relation to the orientation of the crinoid.

From a preliminary examination of the cups mentioned above it seems not improbable that the specimens figured in 1942 (pl. x, figs. 9, 10, and 12), and others like them, may not belong to *Poteriocrinus conicus* Phillips but to an undescribed species. This view is strengthened by the specimen with arms found last year and now illustrated on Pl. III, fig. 8. When found, only a small part of the arms could be detected, the distal region of the arms as well as the cup and column being buried in the limestone matrix. This covering had to be removed. The whole fossil is in a highly crystalline condition, and for that reason is difficult to photograph in a satisfying manner owing to the many scintillating points of light. The distal parts of the arms look rather wide, but this is caused by abrasion when removing the matrix. This specimen confirms the two primibrach plan of the other specimen as well as giving extra evidence of the arm characters. It would appear that the arms only fork once on the primaxils and consist of a series of rather wide and more or less quadrangular secundibrachs, a few tending to be cuneiform. The general appearance and length of the preserved arms suggest that no further branching takes place in this species. In this respect the Coplow form resembles *Poteriocrinus bijugus* Trautschold, now referred by Kirk to a new genus *Pegocrinus* (1940, p. 332), but the cup in the latter species is much lower with less prominent IBB. In the character of the cup the Coplow species has more resemblance to the other Russian species *Moscovicrinus multiplex* (Trautschold) and *Ophiurocrinus originarius* (Trautschold), but differs in the arm structure. While it is not yet quite clear that the new Coplow specimen should be placed under *Poteriocrinus conicus* Phillips or assigned to a new species, one thing is certain, namely that *P. conicus* Phillips must be placed under another genus,

not *Pachylocrinus* as now understood, but probably a new one. Until the full examination of all the cups is completed they are, as a temporary expedient, merely labelled "*Pachylocrinus*" *conicus* (Phillips), the main purpose of this note being to place on record the occurrence of this fine new specimen at Coplow.

Orophocrinus pentangularis (Miller)

Pl. III, figs. 1–3

The specimen assigned to this species consists of a well-preserved theca. It was found in the shale bed about the middle of the section at Coplow (Wright, 1928, p. 248). When discovered, the specimen itself was in great part embedded in a limestone layer, but with care the whole theca was extracted from the matrix. So far as its general character is concerned, this specimen does not seem to differ from *Orophocrinus pentangularis* (Miller) as figured by Etheridge and Carpenter (1886, pl. xv, figs. 5–7) and Bailey (1886, pl. iv, figs. 2, 2*a*). The summit characters are well shown and all five ambulacra are preserved. The plates of the theca are now almost smooth, but faint traces of the characteristic striated ornamentation of the species can be detected. As previously stated, this is the only known blastoid to be recorded from Coplow, but it is perhaps significant to note that the localities given by Etheridge and Carpenter for *Orophocrinus pentangularis* are "Bolland, Lancashire; Clitheroe, Lancashire (Presented by Mr. J. Rofe, F.G.S.)". It is quite possible that one or more of Rofe's specimens may have been found at Coplow. There can be no doubt, however, that the species is a rare one, as is remarked by Etheridge and Carpenter, and this is confirmed by the present specimen, the only blastoid to be found during over twenty years collecting at Coplow. Of course, blastoids are, or were, fairly abundant at the neighbouring quarry of Bellman, which is on a considerably higher horizon than Coplow. D. Parkinson (1926, p. 208) records two species of blastoids from Bellman (*Orbitremites ellipticus* (Sowerby), *Phenoschisma acutum* Sowerby), the names being given on the authority of Professor H. L. Hawkins. I have myself collected blastoids from Bellman, and have seen others from this locality, but none so far belonging to *Orophocrinus pentangularis*, so that the occurrence of the latter species at Coplow is of some interest.

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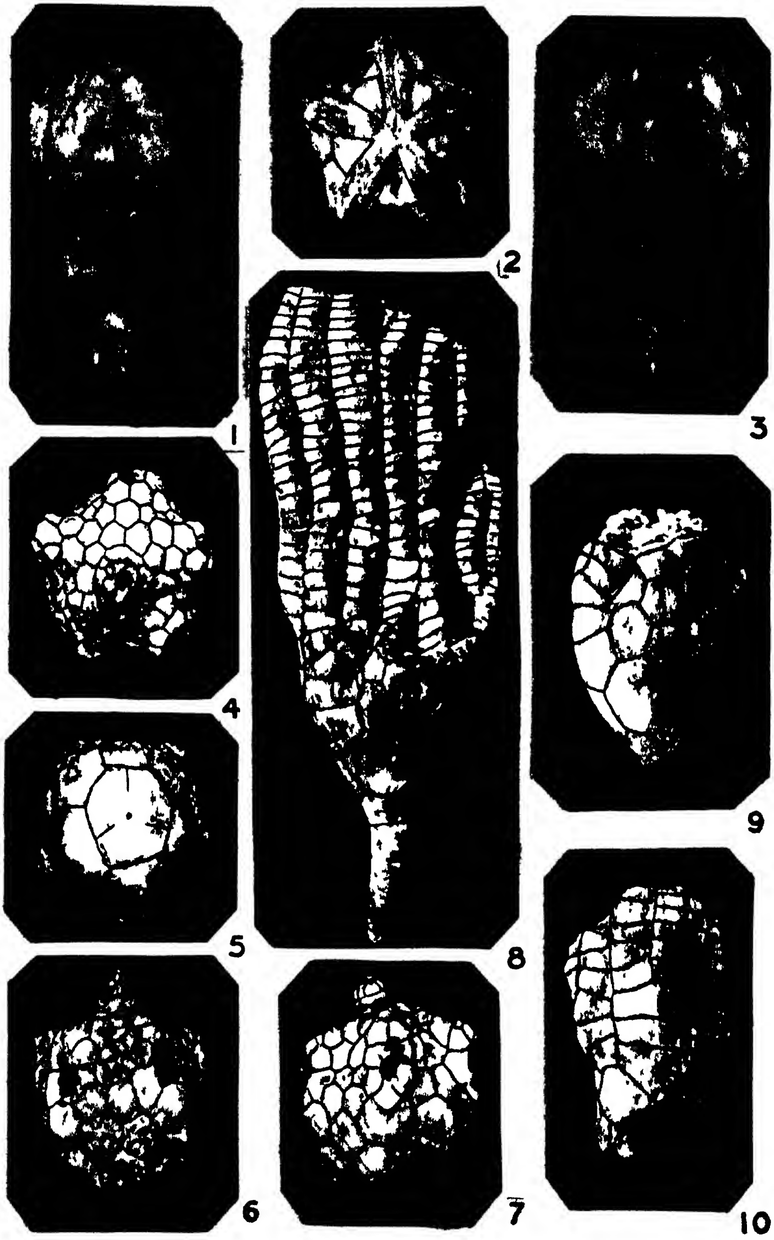

[J. Wright Photo

TWO CRINOIDS AND A RARE BLASTOID FROM COPLOW KNOLL, CLITHEROE.

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EXPLANATION OF PLATE III

FIGS. 1–3.—Posterior, summit, and anterior views of *Orophocrinus pentangularis* (Miller) from Coplow. J. W. Coll., No. 1677. All figs. × 1½ approx.

FIGS. 4–7.—Summit, basal, posterior, and anterior views of holotype of *Steganocrinus westheadi* sp. nov. from Coplow. Stanley Westhead Coll., No. 390. Nat. size.

FIG. 8.—Posterior view of new specimen temporarily referred to "*Pachylocrinus*" *conicus* (Phillips) from Coplow. The left posterior ray, with its two primibrachs, is well shown ; the right posterior and right antero-lateral rays are crushed at their junction with cup and the two primibrachs of right post. ray are squeezed inwards ; a few of the proximal ventral sac plates may also be noted. J. W. Coll., No. 1841. Nat. size.

FIGS. 9 AND 10.—Posterior and anterior views of a specimen referred to the same species, previously figured 1942, pl. x, figs. 9 and 10. J. W. Coll., No. 1116. Nat. size.

On the Relationship between "Fronts" of Regional Metamorphism and "Fronts" of Granitization

By Doris L. Reynolds

TWO important papers, relating to "fronts" of metamorphism, appeared in the *Bull. Soc. Géol. France* during the war years, and may, in consequence, have escaped the notice of many petrologists. The contents of both papers are so closely bound up with the important subject of granitization as to render their review desirable. In the first of these papers, Perrin and Roubault (1941) describe an apparently unconformable boundary between a Triassic conglomerate and an underlying schist. The Triassic conglomerate consists of red quartzite pebbles in a sandy matrix, whilst the schist is a normal low-grade sericite-chlorite-schist of a green colour. Detailed examination of the contact, however, shows that the relations between the two rock types are by no means so straightforward as a cursory examination suggests. Although the contact between the conglomerate and the schist is generally sharp, a close scrutiny establishes the following local but remarkable apparent anomalies: (1) "Xenoliths" of the conglomerate, and isolated pebbles from it, occur within the schist. (2) "Veins" and pods of the schist occur within the Triassic conglomerate. (3) Gradational contacts are sometimes found between the schist and the Triassic sandstone, the schist facies dying out within the space of a few centimetres. On the basis of these observations Perrin and Roubault reach the inevitable conclusion that the metamorphism which gave rise to the schist actually post-dated the deposition of the conglomerate.

They attribute the crumpling of the schist to expansion dependent on metamorphic changes, and the appearance of an unconformable junction to the abruptness of the boundary of the metamorphic zone, the upper limit of which commonly coincides with the base of the conglomerate. They conclude from this coincidence that the conglomerate usually constituted a barrier to the advance of metamorphism. They point out that the propagation of reactions in the solid state, to which they attribute regional metamorphic changes, is dependent on intimate contact within the affected medium, so that a conglomerate, with lack of cohesion, would be likely to form a barrier to the advance of such reactions. On the other hand, the sharp metamorphic boundary at the base of the conglomerate would be most surprising if the reactions had been induced by permeating solutions, gas, "colonnes filtrantes," etc. The phenomena of the conglomerate—schist contact thus support their view that regional metamorphism results from solid reactions.

The importance of knowledge of these findings, and their possible application in any tectonic study, require no emphasis. The schists of Beaufortin, under discussion, form part of an autochthonous mass, and were previously classed as of Hercynian or pre-Hercynian age. This study of Perrin and Roubault, however, establishes the age of the metamorphism which gave rise to the schists as post-Triassic, and consequently of Alpine age.

It is, however, rather with the view of emphasizing the similarity of the phenomena of metamorphism described by Perrin and Roubault, to those of granitization, that this review is written. As the authors themselves stress, the conglomerate—schist junction is a true " front " of metamorphism, exactly comparable to " fronts " of granitization, migmatite fronts, and basic fronts. These various aspects of fronts of different metamorphic grade are ascribed to a unity of mechanism, i.e. to reaction in the solid state. The authors particularly draw attention to the analogy which exists in detail between the aspect of the schist front in the observed example, and the aspect of granitic fronts so commonly regarded as eruptive. Country rock—granite contacts are characterized by phenomena such as xenoliths, exomorphism, pods, apophyses, veins, and network of veins, and the authors point out that these phenomena have been matched, on a similar scale, in the conglomerate—schist contact they describe. In this connection attention should be directed to the similarity between the conglomerate—schist contact of Beaufortin, and the marscoite—granophyre contact in Skye, recently discussed in the *Geological Magazine* (McIntyre and Reynolds, 1947). In this comparison schist corresponds with granophyre and conglomerate with marscoite.

In the second paper Lapadu-Hargues (1945) presents a statistical study of the chemical compositions of the following groups of regional metamorphic rocks, and related granitic types, irrespective of their age : shales and phyllites ; low-grade schists characterized by chlorite and sericite ; biotite-muscovite-schists ; granite-gneiss ; granite and muscovite-biotite-granite. He finds that the various metamorphic grades are not isochemical as hitherto has been widely assumed. With increase in the metamorphic grade, the total alkalis increase, culminating in granite, and Al decreases. In the lower grades of metamorphism, however, it is Na that shows increase, K actually decreasing slightly ; whilst in the higher grades of metamorphism (granitization) both alkalis increase, K showing the greater concentration in the final granites. Fe^{++} and Mg attain their maximum concentration in the lowest metamorphic grades, and decrease through the higher grades. Ca increases gradually with increase in metamorphic grade, and reaches its culmination in granite. Lapadu-Hargues ascribes the variation in the concentrations of the various

elements, in rocks of different regional metamorphic grade, to the difference in mobility of the respective elements under metamorphic conditions. He finds the order of increasing mobility to be : K, Ca, Na, Mg, Fe, and correlates this order with the respective ionic radii of the elements concerned.

Fe and Mg, with the smallest ionic radii, are the most mobile ions and, in consequence, they become concentrated in the lowest metamorphic grades, that is in the least altered rocks situated farthest from loci of granitization. This statistical result, indicative of the high mobility of Fe and Mg, accords with the well-known field observations (Sederholm, Backlund, Wegmann, Reynolds) that granitization involves the displacement of Fe and Mg, these constituents being fixed in a basic front which moves ahead of the advancing front of granitization.

According to Lapadu-Hargues's statistical study, K, with the largest ionic radius of the elements under discussion, has the lowest mobility, and, in consequence, becomes concentrated in granites representing the highest degree of regional metamorphism. Study of actual examples of granitized rocks, however, shows that this is not the whole story relating to the concentration of K. Not only does K show geochemical culmination in granite, but it also migrates, to some extent, with the vanguard of Fe and Mg, appearing in the biotite of the basic fronts. This is exemplified in the biotite-rich rims margining granite veins and pods of migmatite regions, in the biotite-enriched metamorphic aureoles that commonly surround granitic stocks emplaced within pelitic sediments, and in the biotitization of basaltic rocks, epidiorites, and amphibolites. A particularly instructive example of the presence of K in a basic front that advanced into limestone is depicted on plate lxviii of von Eckermann's (1922) dissertation on Mansjö Mountain. The figure illustrates the altered marginal zone of limestone in contact with granite pegmatite. Within this zone of alteration several mineral zones are present. Travelling outwards from the pegmatite to the calcite of the limestone, the mineral zones appear in the following sequence : plagioclase, scapolite, diopside, and phlogopite and apatite. In company with Si, the various groups of constituents of the basic front have migrated into the limestone with the following increasing order of mobility : Na-Ca, Ca-Mg, and Ca-P and Mg-Fe-K-Al.

Both in end-stage granites, and in the basic fronts moving in advance of zones of granitization, concentration of K is a general phenomenon (Reynolds, 1946). Basic fronts are, moreover, characterized by geochemical culmination of the minor constituents Ti, P, and Mn. Mineralogically, as in the Mansjö example, such culminations are made apparent by the high concentrations of apatite and/or sphene.

In future such concentrations can be regarded as clues towards the recognition of a basic front.

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REVIEWS

The East Indian Volcanological Survey

(A Review)

By G. W. TYRRELL, University of Glasgow

THE writer has recently been in communication with Dr. R. W. van Bemmelen, lately returned from Japanese captivity in Java. Dr. van Bemmelen is well known for his geological work in the Netherland East Indies, and for his daring speculations in volcano-tectonics. Since 1940 he has been head of the Netherland East Indies Volcanological Survey, the Bulletins of which were published up to 1941. The latest volume (see below) was issued under Japanese occupation in 1943 as a " war emergency " edition. Van Bemmelen writes : " We, in Indonesia, have suffered in the Japanese camps and many died in the most terrible circumstances. Though most of us lost near relatives, most happily I got my wife and son back after three years of separation. We lost all our personal belongings but our great luck is that we are now healthy and safely back in Holland."

I have received from him a copy of the " Bulletin of the East Indian Volcanological Survey for the Year 1941 (Bulletins Nos. 95–98) ", War Emergency Edition 1943 (pp. 110, with 42 figs. and XXIV tables), by Dr. R. W. van Bemmelen. The volume has a heading in Japanese which runs :

KOGYO JIMUSHO

Bandoeng

CHISITSU-CHOSAJO (Kwasan Chosabu)

meaning : Bureau of Mines, Bandoeng. Geological Office (Volcanological Survey).

This is an extraordinary piece of work considering the conditions under which it was prepared for the press. It speaks volumes for the courage and endurance of van Bemmelen and his colleagues. Concerning it van Bemmelen writes : " This Bulletin, prepared during the Jap occupation as a prisoner of war for a daily payment of 10 cents, is a war emergency edition printed in a native press-room and bound by my own personnel. However, knowing that the work of twenty years of the Netherland-Indian Volcanological Survey would be interrupted for some time to come, and not knowing whether any of us would survive the barbarous treatment of the Japs, I tried to terminate this period with a Bulletin in which many provisional results were published, and also a complete historical register of the volcanic phenomena of the Indonesian Archipelago."

An Introduction to the work in Japanese was written by Ikebe. A translation of this by van Bemmelen is as follows, and shows that the

Japanese were by no means insensible of the scientific and social value of the Dutch geological work in Java :—

" The volcanoes in the East Indies, especially Java, are the most active in the world. Volcanological research must therefore be continued under the future government of the East Indies, to provide for the protection of the population against danger, and for the development of the sources of energy which accompany volcanic activity.

The former Netherlands Indian Government had founded for these purposes a Volcanological Survey as a branch of the Geological Survey (Mining Bureau), with permanent observation posts on the most important active volcanoes. This Survey applied itself to volcanological research, observation of volcanic activity, and the prediction and prevention of calamities. The results of these researches were published in the ' Bulletins of the Netherland Indies Volcanological Survey ' and the ' Vulcanologische en Seismologische Mededeelingen '.

This work has been written by the chief of the former Volcanological Survey, van Bemmelen, as the Annual Report for 1941. The historical data on the activity of all volcanoes of the East Indies as far as known have been collected and listed in this book ; also data on recent outbursts, geological maps of volcanoes, etc.

Believing that the results of the former Netherland Indies Volcanological Survey should be considered in their broader aspects, and that they will supply important material for future research in this field, I have ordered it to be printed.

March, 1943.

Deputy Director of the Geological Survey (Bandoeng) : Geologist of the Geological Survey.

IKEBE."

The Bulletin is divided into two parts ; General, and Special. The former contains two papers ; (A) Register of the Localities of Volcanic Activity in the East Indian Archipelago, and (B) Preliminary Historical Register of Volcanic Activity in the East Indian Archipelago (A.D. 1000–1941). The latter has been compiled by W. A. Petroeschevsky. The localities of volcanic activity number 130, of which 30 are situated in Sumatra, 35 in Java, 22 in the Lesser Sunda Islands (Bali, Lombok, Soembawa, Flores), 7 in the islands between Flores and Wetar, 18 in the Moluccas and New Guinea, and 18 in Celebes and the Sangihe Archipelago. Borneo is apparently devoid of recent volcanic activity.

The register of historical volcanic activity from A.D. 1000 to A.D. 1941, while it is regarded as still provisional, nevertheless " gives a tolerably complete general picture of our present knowledge of the

history of the volcanic activity ". Eruptions and periods of increased activity number in all 1,952, only 89 of which are recorded as having taken place before 1700 ; 80 between 1700 and 1799 ; 157 between 1800 and 1840 ; and 1,626 between 1841 and 1941. This, of course, does not mean that volcanic activity has increased greatly in the last century, merely that records have been more often made and better preserved.

The Special Part records observations at a number of volcanoes during 1941, and deals with the geology of some of them in detail. Anak Krakatau is dealt with at considerable length for the period 1927–41. Within that period the new volcano experienced no fewer than 52 " phases " of ash eruption, a " phase " being a period of eruption without an interval of quietude lasting more than a fortnight. Chemical analyses show that each cycle of activity at Krakatau begins with basalts (SiO_2, 51–54 per cent), and passes gradually to tridymite-andesites and dacites (SiO_2, 65–70 per cent), when cataclysmal volcanic outbursts associated with collapse and caldera formation take place. Since Anak Krakatau, which has been built up by basaltic eruptions, shows no sign of change towards more acid types of lava, it is thought that eruptions of the disastrous 1883 type are not yet to be feared.

The Merbaboe (Java) volcano has been mapped in detail by Dr. van Bemmelen. It is built mainly of olivine-basalts and augite-andesites, followed at a late stage by very thick (100 m. +) viscous flows of augite-hypersthene-hornblende-andesite. The latter more or less choked the vent, and upward pressure of the still rising magma burst the cone along radial fissures, between which three sector graben have developed with the aid of erosion.

The neighbouring and better-known volcano of Merapi is an active cone at the present day, with a daily output of lava during 1940 estimated at about 15,000 cubic metres. A systematic geological survey of the volcano was made in 1941, which has resulted in an excellent map reproduced as Fig. 17. The Merapi lavas vary from olivine-basalts to hypersthene-hornblende-andesites, and their chemical composition is illustrated by twenty full analyses.

There follows a number of descriptions of volcanic regions all excellently illustrated by geological maps and sections. The Soropati-Telemojo complex (Java) consists of a volcanic ruin (Soropati) partially buried beneath the northern base of the Merbaboe volcano and the young Telemojo cone. Oengaran is practically extinct ; its history is characterized by periods of growth alternating with collapses of the volcanic cone. Oengaran is surrounded by a curved fault-system superficially resembling the ring faults (cauldron-subsidences) of the Scottish Old Red Sandstone and Tertiary volcanoes, but the structure and mechanism of the Javanese example is quite different. These faults

are interpreted as gravity slip faults due to subterranean magmatic spreading in a north-easterly direction.

Fig. 24a is a valuable geological sketch map of eastern Central Java which, with a correlated physiographical map (Fig. 24b), illustrates the succession of the Oengaran, Soropati, Telemojo, Merbaboe, and Merapi volcanoes. These volcanoes are genetically connected and have developed along a N.N.W.–S.S.E. fissure (the Oengaran-Merapi Rent).

Semeroe is also the object of a detailed investigation illustrated by seven maps and sections, and nine chemical analyses of its lavas. Geotectonic analysis leads to the conclusion that Semeroe is situated at the intersection of an E.–W. fault-system parallel to the geanticline of Java, and a transverse N.–S. faulting caused by an axial depression to the east.

Geological maps are also given of the Malang Residency (Eastern Java) covering the famous ring-fault system of the Tengger ; of the Idjen Group (Java) ; and of the Lokon-Empoeng twin volcano of Northern Celebes, of which five new analyses illustrate again the familiar succession from olivine-basalt to augite-hypersthene-andesite.

The production of this work under the most adverse circumstances, yet with evidences of careful preparation and meticulous attention to detail, is a tribute at once to the physical and mental endurance of van Bemmelen and his colleagues, and to their scientific acumen and enthusiasm. For example, the Bulletin is very free from mistakes and misprints although it is written in the comparatively unfamiliar English tongue. The illustrations have obviously caused most trouble ; nevertheless they are numerous and of good quality. Many of them are just pasted in on their edges over blank spaces which, under happier circumstances, they would have occupied. But this, of course, has been due to the cramped and unfavourable conditions of publication. This volume, full of valuable new volcanological observations, will take its place as a monument to the unconquerable spirit of Holland and of its scientific men.

A Census of the Determinable Genera of the Stegocephalia. By E. C. Case. *Transactions of the American Philosophical Society, Philadelphia,* Vol. XXXV, Part IV, 1946. Price $1.25.

The extensive work which has been carried out on the Stegocephalia in recent years, and which includes both notable discoveries and important revisions of old material, has cleared up a number of important problems, but it has increased still further the problems of the taxonomy of the group. In this work Professor Camp has listed those genera which he considers determinable, summarized their characters, remarked on the classifications adopted by recent writers,

and has illustrated the skulls of the majority from current sources. The work started from an attempt to evaluate published information, but served largely to draw attention to conflicting opinions regarding the interpretation of specimens, the extensive use of inadequate material for taxonomic purposes, and the difficulty of deciding the characters to be used for classification. The list is introduced by discussions of these problems and by a note on the stratigraphy. The difficulties resulting from the use of too imperfect material as types and from inadequate preparation and description are met with in other groups and, while the list is of value for its own sake, it serves a most useful purpose in emphasizing them. The further difficulty of recognizing growth stages of extinct animals, which is particularly apparent in the study of the Stegocephalia, is likely to become increasingly apparent in other groups in the future.

F. R. P.

Publications of the *Mijnbouw in Nederlandsch-Indië*

By J. B. SCRIVENOR

1. DE GEOLOGIE VAN HET CENTRALE EN OOSTELIJKE DEEL VAN DE WESTER-AFDEELING VAN BORNEO. C. P. A. ZEIJLMANS VAN EMMICHOVEN; with an appendix by G. H. R. VON KOENIGSWALD on ammonites and aptychi of the Lower Cretaceous.
2. DE GEOLOGIE VAN HET WESTELIJKE EN SUIDELIJKE DEEL VAN DE WESTER-AFDEELING VAN BORNEO. R. W. VAN BEMMELEN. Both papers in the *Jaarboek van het Mijnwezen in Nederlandsch-Indië*, 1939, Batavia; with a geological reconnaissance-map in six sheets, scale 1 : 250,000, two plates of sections, scale 1 : 250,000, and a route-map, scale 1 : 500,000. Both papers have English summaries.
3. NEUE PITHECANTHROPUS-FUNDE, 1936–38. EIN BEITRAG ZUR KENNTNISS DER PRAEHOMINIDEN. G. H. R. VON KOENIGSWALD, with a foreword by F. WEIDENREICH. No. 28 of the *Wetenschappelijke Mededeelingen*, 1940.
4. VULKANOLOGISCHE ONDERZOEKINGEN IN OOST EN MIDDEN FLORES. CH. E. STEHN. No. 13 of the *Vulkanologische en Seismologische Mededeelingen*, 1940. With an English summary.

THOSE interested in the geology of the Netherlands East Indies will congratulate the *Mijnbouw in Nederlandsch-Indië* on the resumption of publication after the Japanese occupation. Like all their publications and maps, those mentioned above are beautifully produced and important contributions to the scientific literature of the East Indies. The 1939 volume of the *Jaarboek van het Mijnwezen* contains two papers on the geology of West Borneo, excluding the

part described by Wing Easton in 1904, but including the basins of the Sarawak and Sadong rivers in British territory and also the part of Sarawak that abuts on Dutch Borneo near and at Tanjong Datoh. Van Bemmelen's paper is based on 2,572 specimens collected by L. H. Krol and other Dutch geologists. Krol died in 1933 before he could publish his work and this was delegated to Van Bemmelen. It is mostly petrological, containing no palaeontological information. Work by W. F. Gisolf and P. Esenwein on some of the specimens is included.

Zeijlmans van Emmichoven's paper contains palaeontological information resulting in the revision of previously held views about the age of the rocks and also establishing the existence in West Borneo and Sarawak of Permocarboniferous strata with *Fusulina*, *Pecopteris*, and *Calamites*. No conglomerates have been found in these Permocarboniferous beds, an important point to be noted in British Malaya. The Upper Trias contains *Monotis*, *Halobia*, *Steinmannites*, *Cedroxylon* and *Dadoxylon*. The age of Molengraaff's Danau Formation is revised. He considered these rocks to be Jurassic and perhaps Triassic ; but the author says that the formation as a whole is to be correlated with the Permocarboniferous and Upper Trias. He adds that Molengraaff's quartzites, sandstones are comparable with the Upper Trias and that this disposes of the objection " to an abyssal facies of the radiolarites ". He says also : " radiolaria, formerly considered as a criterion of abyssal deposits, have lost their significance in this respect. Evidence of a deep sea character . . . are fish teeth with dissolved dentine, manganese nodules, and especially the uniform development of the siliceous rocks in a rather narrow, very long belt." The reference to the abyssal facies of the radiolarites is not clear. Jurassic rocks are now held to be unproved in any part of West Borneo or Sarawak, not even in the basin of the River Landak and other localities where Wing Easton claimed Jurassic rocks on the strength of *Protocardia*, *Exelissa*, and *Perisphinctes*. *Alectryonia amor* in Sarawak was claimed by R. B. Newton as Middle Oolite and *Perisphinctes*, found by the reviewer at Bau, in Sarawak, was considered by G. C. Crick to show Jurassic age. Now, however, all the supposed Jurassic outcrops in Sarawak are mapped as Cretaceous with a numerous fauna including *Orbitolinae* and plant remains. *Duvalia*, confined to the Upper Jurassic and Lower Cretaceous, was found, but with this exception the fauna is believed to be Upper Cretaceous. Cretaceous rocks are widespread in West Borneo and the whole formation is correlated with the Utatur Stage in South India. Palaeogene and Neogene strata are described. Descriptions of crystalline schists occupy a large part of both papers, some being of Permocarboniferous and Triassic age. Staurolite and sillimanite schists occur. The plutonic rocks range from granite to

gabbro and include two types rarely mentioned in petrological literature, mangerite and opdalite, the former more basic, the latter more acid than tonalite. Hypabyssal and effusive rocks are described. Tectonic movements are recognized in Permocarboniferous and Triassic times (owing to strong, close folding these rocks are not always shown separately on the map); in Jurassic times shown by the transgression of the Cretaceous over Triassic and older formations; in Cretaceous and Palaeogene times; while weaker movements took place later.

The map, published in a separate cover, is very well printed and has a replete index. It might be suggested that the addition of numbers or letters or both to the many colours employed would have been an improvement.

Koenigswald's paper on new discoveries of *Pithecanthropus* can be adequately reviewed only by a specialist in the subject, but its scope can be indicated here by reference to the English foreword by Franz Weidenreich. He discusses the affinity of *Sinanthropus* and *Pithecanthropus* and Dubois's inability to recognize close relationship or to admit that the skull found by Koenigswald at Sangiran was the skull of a genuine *Pithecanthropus*. Weidenreich examined all the new discoveries of *Pithecanthropus* and also the remains of *Homo soloensis*. He says: "*Pithecanthropus*, so far as now represented by skulls and lower jaws, undoubtedly is a rather primitive hominid form with the closest relation to *Sinanthropus* and like the latter of extraordinary variability, apparently partly due to sexual differences. Which of these two types —all characteristics combined—represents the more primitive one can only be determined when a greater number of remains of both forms become known. . . . Compared to the Neanderthal group, *Pithecanthropus* and *Sinanthropus* undoubtedly represent a more primitive evolutionary phase. It is all the more important that *Pithecanthropus* shows a series of remarkable affinities to the Javanese Neanderthal form of *Homo soloensis*, which in turn suggest that the latter represents the immediate sequence to *Pithecanthropus* in the evolutionary stage of the Java Man."

The fourth paper, with 16 photographs, 4 plates, and numerous text-figures, contains as its chief feature the author's account of the 1932 and 1933 eruptions of Lewotobi Lakilaki (the male Lewotobi: there is a female also but she remained quiet!), incorporating information derived from Father L. Flint of the St. Arnoldushoeve Catholic Mission. It was found that a branch of the lava-flow had slid down as a coherent mass along the volcano-slope and that dust-clouds were caused by such sliding and by falling avalanches of lava. Several other volcanoes are described, the last being Mount Ija at the end of a peninsula on the west of Ipi Bay. Activity of fumaroles had increased and there was a risk of avalanches of the volcano-mantle causing

sea-waves that might endanger life and property. Notable among the photographs are some of crater-lakes.

ABOUT THIS EARTH. An Introduction to the Science of Geography. By F. KINGDON WARD. pp. 168. London: Jonathan Cape, 1946. Price 7*s*. 6*d*.

This is not an elementary textbook of geography. Its object, as stated in the preface, is to explain what geography is about. The author, the well known botanical explorer who has added so many wonderful new plants to our gardens, is well qualified for his task. Besides being the son of a Professor of Botany at Cambridge, he has the advantage of having studied geology there, so that he is able to realize the geological basis of the geography of the countries that he has explored. Here and there his geology is open to criticism, as in the statement that the floors of the oceans are mostly granite, while the basis of the continents is basalt, and the not uncommon error that Ruwenzori is a volcano. But this is not important in view of the main trend of the whole book.

Like so many recent writers who have seen other lands, the author is much preoccupied with soil-erosion and soil conservation, one of the most important problems now facing mankind. In the British Isles the loss of land suitable for agriculture and forestry is mainly due to the growth of towns, old and new, to airfields and military training grounds, and to some extent to the operations of preservation societies devoted mainly to the interests of the hiker. These same societies also cause endless trouble when any attempt is made to develop what water power we do possess, and so to save coal. Now there is none too much cultivable land in the world. As is emphasized in this book, two-fifths of the whole land surface of the globe is useless for agriculture, most of it because it is too hot and dry, but a large proportion because it is too cold and wet. And it has to be realized that in spite of an enormous development of irrigation in many parts of the world, man himself has done a lot to increase the useless area, by reckless deforestation, over-cropping, overstocking and over-grazing, uncontrolled grass burning, and so on. On all these points this book is most illuminating, as being the work of a man who has seen much.

There are also some excellent chapters of a botanical trend, as, for example, the descriptions of tropical evergreen rain forest and its exact opposite, the alpine zone, as so well developed in South-East Asia, the scene of the author's main work. Some of the sections devoted to the great rivers of that part of the world are extremely graphic and instructive, especially the discussion of why so many of

them cut through enormous mountain ranges in some of the most wonderful gorges in the world. An amusing suggestion is that it might be possible to divert the Mekong into the Salween, which is described as a peculiarly useless river from the navigation point of view, without even a fertile delta, though it is uncertain whether the result would be an improvement or not. It is also pointed out that there is much scope in that part of the world for organizations like the Tennessee Valley Association.

The last chapter is devoted to the possible applications of atomic power towards improving geographical conditions. It is concluded that atomic bombs could not make it rain in dry deserts, and that artificial cataclysms of that kind cannot perform geological operations quickly, whatever may be the outcome of future applications of atomic energy in less spectacular forms to more normal processes of engineering.

R. H. R.

SOLVING EARTH'S MYSTERIES. Or Geology for Girls and Boys. By H. H. SWINNERTON. pp. 220, with 181 figs. and a coloured geological map. London, G. G. Harrap and Co., Ltd., 1946. Price 8*s*. 6*d*.

It has often been said how much is lost by travellers and holiday makers who know nothing of the geological basis of what they see. The geologist can always find an occupation of interest, even on a wet day at a not-too-sophisticated seaside place, which most people would find inexpressibly boring. This book is intended to provide such a basis, especially for young holiday makers. It is written in the simplest language compatible with accuracy, and profusely illustrated. Although the author is a distinguished palaeontologist, he does not introduce any names of fossils in the first two-thirds of the book, but begins with rocks, soils, and structures. The emphasis on soils in an elementary book is commendable, as there is always some soil to be found everywhere, and there are many points worthy of study even in such simple matters as soil-creep and minor land-slipping.

It is a difficult task to write a summary of geology in 220 pages, of which about a third are figures, but the author has been very successful, by a miracle of compression, in providing a book likely to rouse interest in the subject among young people. The line drawings are very good, but it is a pity that some of the half-tones, including many taken from Grabau's *Textbook*, are so smudgy that it is hard to make out the essential point, e.g. in a restoration of a three-toed horse (fig. 163*a*), no toes can be seen. There are perhaps rather too many of these American restorations of " Prehistoric Monsters ".

R. H. R.

CORRESPONDENCE

HERCYNIAN Fe-Mg METASOMATISM IN CORNWALL

SIR,—Knowing something of Miss Reynolds's views on petrogenesis from her previous essays on this subject, I am not at all surprised to find the disagreement she records (*Geol. Mag.*, 1947, pp. 33–50) with Flett and Tilley's derivation of the greenstone and cummingtonite-bearing hornfelses of the Kenidjack-Botallack area, Cornwall. Rocks long recognized as greenstones derived by thermal metamorphism of sheared basic igneous rocks, and mapped as such by the Geological Survey, are now reinterpreted by her as altered limestones ; and the cummingtonite-anthophyllite assemblages intimately associated with the greenstones and regarded as their derivatives are classed as altered calcareous shales, desilicated and " basified ", if I am not mistaken, by action of an iron front of regional character which penetrated them and the associated " limestones " prior to the emplacement of the Land's End granite.

I may say at once that it is difficult to believe, on reading her contribution, that Miss Reynolds has found real opportunity to acquaint herself at first hand with the rocks she attempts to reinterpret ; conjuring with von Wolff diagrams, ill suited for the purpose, provides, it seems, the real enlightenment, here as elsewhere. Nevertheless a critical field study taken in time might perhaps have saved her from this strange and fanciful version of the Cornish geological record.

I do not propose to dwell further on so gross an error—it may well be left to seek its own level in the heavy score of misinterpretations already standing to the credit of " front " petrology.

C. E. TILLEY.

DEPARTMENT OF MINERALOGY AND PETROLOGY,
THE UNIVERSITY, CAMBRIDGE.
10th February, 1947.

CRYSTALLIZATION OF PLUTONIC AND HYPABYSSAL ROCKS

SIR,—May I make the following reply to Dr. Nockolds's letter published in the last number of the *Geological Magazine* ?

(1) In his paper Dr. Nockolds stated that discontinuous reaction " cannot happen in a eutectic system ". He now claims to have meant no more than that a discontinuous reaction point is not a eutectic point. Why then cite Dr. Bowen in order to support a thing so self-evident ? What he did write was bound to lead the reader to assume that it was for systems with one or more eutectics that he used the term " eutectic system ".

(2) After two phases have begun to crystallize together, disappearance of one of these by reaction with the liquid necessitates simultaneous precipitation of a new phase. The number of crystalline phases may increase, but cannot diminish, in a cooling system. What is asked of Dr. Nockolds is an explanation, not of incongruent melting, which is indeed familiar to every petrologist, but of the successive reductions in the number of phases during the periods between the crystallization of (i) olivine and augite, (ii) rhombic pyroxene and hornblende, and (iii) augite and biotite ; how can two phases which crystallize together at one temperature become a reaction pair at a lower temperature ? Unless assertion constitutes proof, the statement in Dr. Nockolds's reply that the phase-boundary curve *might* be divided " into two parts, one of reaction, and one of simultaneous crystallization " is not an explanation.

(3, 4, and 5). As the eutectic of " the imaginary polydimensional space diagram " is approached and the ferromagnesian minerals cease " to all intents and purposes " to crystallize, so the amount of residual liquid becomes, " to all intents and purposes", zero. It is mechanically impossible for such a small amount of liquid to be separated from the crystal aggregate without the fracturing of crystals throughout a large volume. What evidence does Dr. Nockolds have that such wholesale crushing has taken place in the Caledonian plutonic complexes ?

Dr. Nockolds has stated (1940, p. 503) that with complete separation of the most basic material which could reasonably be assumed to have crystallized early, i.e. with complete fractionation, " the parent magma *chosen* is capable of yielding approximately 30 per cent of normal granodiorite " (my italics). We are now told (1946, p. 215), and the point is emphasized (1947, p. 60), that the degree of fractionation was " not particularly strong ". " A moderate but not particularly strong degree of fractionation " is only a qualitative statement, but it indicates that the process of crystal differentiation, in which Dr. Nockolds believes, is unlikely to produce more than 10–15 per cent of granodiorite and to separate even this amount, the crystal aggregate must be crushed. Associated with large bodies of granite one would therefore expect truly gigantic masses of basic rocks. Where are these ?

In the discussion on Dr. Nockolds's Garabal Hill paper, Dr. J. Phemister pointed out (1940, p. 510) that " as a matter of fact, over 80 per cent of granodiorite was visible in the Garabal Hill complex, and, taken generally, the percentage must be still higher for the whole series of Lower Old Red intrusions ". Although never having replied to that criticism directly, Dr. Nockolds has warned us (1940, p. 503) of " the danger of drawing conclusions about the relative abundance of rock types from their present outcrops ", but he admits that " even so, there can be little doubt that granodiorite is relatively abundant ",

i.e. relative to the basic rocks. Now, this problem is of the utmost importance in the evaluation of the hypothesis of crystal differentiation. At the present surface of the earth plutonic rocks are exposed which originated at various depths, and granitic rocks are found to be relatively and even increasingly abundant in the deepest exposures. We must assume, then, that Dr. Nockolds believes that the main bodies of basic crystal accumulates, even those corresponding to granites of relatively shallow depths, lie deeper than any level yet exposed by denudation. Has Dr. Nockolds formed an estimate of the depth in miles through which these basic crystals have sunk, or of the time between the initiation of crystallization at a high level in the earth, the settling out of the basic crystals (taking into account the enormous increase in viscosity at those great depths), and the first eruption of crystal accumulate back again to the upper part of the earth's crust ? If the Caledonian plutonic rocks owe their origin to this process, one is tempted to inquire whether 3,350 million years is not a conservative estimate of the age of the earth !

The analogy of " stones " sinking to the bottom of the magma chamber is inapt. Supporters of crystal differentiation have never explained how less dense rocks detached from the roof can sink through an alleged pyroxene-mica-diorite magma. That such rocks could sink through intruding crystal aggregates (cf. 7) with still higher density and viscosity seems even more improbable. It is the sinking of " corks " not of " stones " in which we are asked to believe.

It should be pointed out that four component phase diagrams should consist of separate tetrahedra for each temperature and for each pressure. If four component systems, requiring five dimensions, are compressed into three dimensions and then projected on to two, as Dr. Nockolds has done, they surely necessitate some word of explanation and justification for the benefit of readers who were assumed to be familiar only " with the more elementary types of phase diagram ".

(6) It is interesting to observe that in Dr. Nockolds's paper on " The Granitic Cotectic Curve ", published in the last number of the *Geological Magazine*, he appears to be forced to call on " potash metasomatism " and " albitization " to account for certain of the aplites with which he treats. Does Dr. Nockolds believe that such K and Na migrations are examples of solid diffusion ?

(7) If the basic roof rocks were formed by the sinking of the early and heavy crystals to the bottom of the magma chamber, and the subsequent intrusion of the crystal aggregate through the overlying liquid and into the solid country rocks above, then explanations are required for (i) the postulate that, when the " squeeze " acted on the system and caused intrusion, the solid and not the available liquid was mobilized, (ii) the implication that the " squeezes " acted on each

Caledonian plutonic mass at the same stages in their crystallization sequences, and (iii) the mechanics of intrusion of a crystal aggregate, e.g. by stoping or salt-dome mechanism, etc., and not forgetting the space problem.

The paucity of references in the literature suggests that many petrologists have overlooked the remarkable statements made by Dr. Nockolds (1940, pp. 504–5) on this subject : " In the early stages of differentiation, the crystals are literally abstracted from the liquid. . . . The intrusion of . . . crystals with little or no magma gives rise to those types whose composition is believed to be governed . . . by crystal accumulation. In the later stages of differentiation, however, the amount of crystalline material in the magma reservoir becomes much greater and finally exceeds the liquid in quantity. Under these conditions it is the magma which now moves relatively to the crystals." In brief, when the magma is in excess of the crystals, it is the crystals that intrude (presumably through the overlying magma) ; when the crystals are in excess of the magma, it is the magma that intrudes. This is an example of the type of mechanics which Dr. Nockolds is obliged to employ in order to make crystal differentiation work.

Dr. Nockolds has written (1940, p. 501) : " The mode of intrusion of the almost pure subtractive types is extremely difficult to visualize. This difficulty is sometimes used as an argument against such rocks being crystal accumulations and against the hypothesis of crystallization-differentiation. The fact is usually overlooked that it is equally difficult to account for them in any other way." Dr. Nockolds ignores the fact that such rocks are very easily accounted for by the hypothesis that they represent the zone of fixation of the basic constituents, driven from the zones of granitization ; that they are examples of the much ignored but all-important phenomenon—the basic front.

(8) It is unreasonable for Dr. Nockolds to suggest that the Loch Doon evidence was used in my letter as an argument against his conclusions when, in fact, none of that evidence had been given. Loch Doon was mentioned merely to indicate that an explanation other than that supported by Dr. Nockolds is possible, and thus to relieve the necessarily negative criticism which formed the main substance of my letter.

If, as Dr. Nockolds states, crystal differentiation " explains why rocks of more extreme acid character are not found here or in other igneous rock series ", what explanation is advanced for the origin of the quartz veins which certainly are found here ?

" The facts brought forward in connection, more especially, with the light constituents indicate a most striking similarity of behaviour between these constituents in *natural magmas* and in experimentally determined melts. Is it an accident that the *last residual liquids* of

natural magmas should lie on the ternary cotectic curve ? " (my italics). Such remarks by Dr. Nockolds are excellent examples of *Petitio Principii*, a fallacy all too common in discussion on the plutonic rocks. We can study plutonic rocks, but we cannot study plutonic magmas. To maintain that a given plutonic rock originated from a magma is no more than a hypothesis, and as such requires evidence for its support. If the evidence favours a magmatic origin then the question of the origin of the magma arises. Supporters of the hypothesis of solid diffusion do not deny that there have been magmas ; they trace the stages leading up to their origin. Dr. Nockolds evidently forgets that the " reasonable scientific hypothesis " that he supports is based on his *choice* of a parental magma.

DONALD B. MCINTYRE.

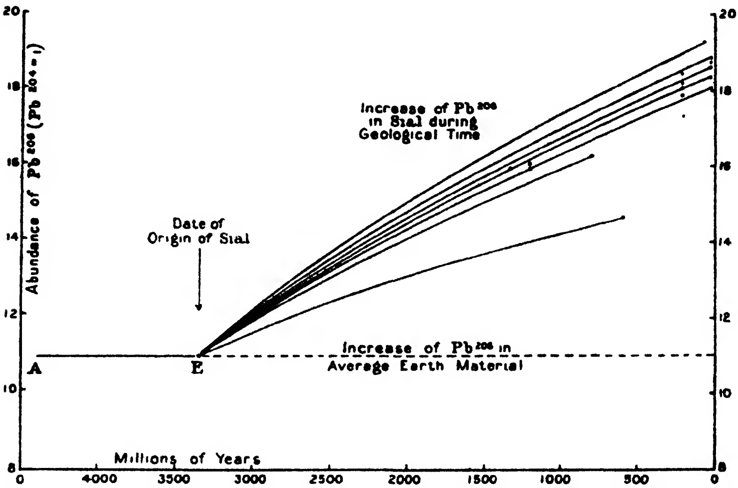
GRANT INSTITUTE OF GEOLOGY,
UNIVERSITY OF EDINBURGH.
10th February, 1947.

AN ESTIMATE OF THE AGE OF THE EARTH

SIR,—In his letter to the *Geological Magazine* (this volume, p. 57) Professor Kuenen expresses his belief that my recent estimate of the age of the earth refers not to the time of origin of the earth as a planet, but to the time of origin of " the materials forming the earth ". I had not overlooked the fundamental distinction to which Professor Kuenen directs attention ; this and many other points not yet discussed will be fully dealt with in a detailed paper that is now being prepared. Meanwhile, however, I must make it quite clear that what I have determined is the most probable age of the rock material containing that dispersed rock-lead from which—by localized concentration brought about during various metallogenic epochs—lead ores have been formed. Geological and geochemical data (and also the results of the investigation under discussion) all consistently indicate that the source of the lead ores is the sialic part of the continental crust ; or, in other words, that lead ores represent concentrations from the granitic layer and its sedimentary and metamorphic derivatives. Accordingly, the age I have determined refers to the time when the granitic layer separated from average earth material during the consolidation of the globe. It is generally considered to be highly probable that the earth was originally gaseous and that the period of consolidation, up to the time of formation of a solid crust, was relatively short. Jeffreys, for example, estimates that " the earth probably became solid within 15,000 years of its ejection from the sun ". Even if this estimate were wrong by a factor of a thousand, the age of the granitic layer would not be appreciably different from the age of the earth.

The point raised by Professor Kuenen would be a serious one—and would indeed make the problem insoluble—if the ratio Pb/U in sialic material were the same as in average earth material. It is, however, easy to show that in sialic rocks the ratio Pb/U is far lower (i.e. U is relatively much more abundant) than in average earth material.

The average U content of earth material can be assessed by considering the outward heat flow. This amounts to about 40 cals./sq.



cm./year, of which not more than half can be ascribed to the heat generated by the disintegration of uranium, the balance being derived from Th and K and from ancestral heat. The rate of production of heat from 1 gm. U in equilibrium with its radioactive descendents (UI and AcU series) is ·74 cals./year. Thus in the long pyramidal pencil beneath each sq. cm. of the continental crust down to the earth's centre the total amount of U is 20/·74 = 27 gm. The mass of the pencil is $6{\cdot}36 \times 10^8 \times 5{\cdot}53/3 = 11{\cdot}7 \times 10^8$ gm. The average U content of this material is therefore ·023 p.p.m. In sialic rocks the average U content is about 3·5 p.p.m.

For lead the relevant data are :—

Sedimentary rocks . .	20 p.p.m.	(Goldschmidt, 1937)
Granitic rocks . . .	20 „	(Sandell and Goldich, 1943)
Basaltic rocks . . .	5 „	(„ „ „)
Stony meteorites (silicates) .	2 „	(Goldschmidt, 1937)
Stony meteorites (troilite) .	60 „	(„ „)
Nickel-iron meteorites .	60 „	(„ „)

On the meteorite analogy (taking the mass ratio earth/core as $\frac{1}{3}$) the average Pb content of the earth would be 22 p.p.m., without taking

troilite into account. Only three determinations of Pb in ultrabasic rocks have been made (Hevesy and Hobbie, 1931) and these, so far as they go, suggest that such rocks contain more lead than stony meteorites. The average Pb content in the real earth is therefore likely to be higher than 22 p.p.m.

From the available data it may reasonably be concluded that sialic material contains about 150 times as much U as average earth material, and that Pb/U in average earth material is probably more than 150 times higher than in sialic material, possibly 250 times higher. This means that since the moment when the granitic layer came into existence, its dispersed content of primeval lead has been modified by continuous additions of Pb^{206} and Pb^{207} (besides Pb^{208} from Th—not here considered) at a rate at least 150 times as great as it would have been in average earth material, if the latter had continued to exist as such. This striking and sudden change in rate is made clear by the adjoining diagram, which shows the variation in time of the abundance of Pb^{206} (relative to $Pb^{204} = 1$) in the two kinds of material. A similar diagram could be constructed to show the corresponding increase of Pb^{207}. The point E indicates the abundance of Pb^{206} (x) at the time (t_0) of the origin of the granitic layer. If average earth material had previously existed (e.g. in the sun) its abundance of Pb^{206} would have varied—almost inappreciably—along the line AE. If the average earth material had continued to exist, its abundance of Pb^{206} would have varied along the dotted line from E to the present day. But in the sialic material that originated at E, Pb^{206} varied along the curves linking E to the points representing the abundances of Pb^{206} in actual lead ores of known ages. There are several such curves (not all are drawn) because the regional distribution of U in sialic material is not uniform.

My method of determining the age of the earth is essentially this: starting with the points representing the abundances of Pb^{206} (and of Pb^{207}) in dated lead ores, the point E is found at which the curves most nearly come to a focus. This focus refers only to the material of the granitic layer and is quite independent of any considerations involving the average material of the earth. The time of origin of the granitic layer is, in fact, a zero point from which the age of the granitic layer can be measured, and that, for all practical purposes, is indistinguishable from the age of the earth.

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ARTHUR HOLMES.

GRANT INSTITUTE OF GEOLOGY,
UNIVERSITY OF EDINBURGH.
11th February, 1947.

SIR,—My criticism of Holmes's paper, although evidently unfounded, has induced him to clarify a point that I know had troubled others besides myself, in advance of his detailed treatment. In spite of being a wiser man, I need therefore be no sadder.

PH. H. KUENEN.

GEOLOGISCH INSTITUUT,
RIJKS-UNIVERSITEIT,
TE GRONINGEN.
24th February, 1947.

CHILLED AND "BAKED" EDGES AS CRITERIA OF RELATIVE AGE

SIRS,—As an old campaigner, who is for ever grateful for the assistance he has received from corrections by fellow-workers, may I say how much I enjoyed the January–February number of the *Geological Magazine* ? There are at least two divergent schools of petrology at work in the British Isles, and the more we get together, so as to tackle simultaneously identical problems, the quicker we shall arrive at satisfactory agreement. The principle of a reserved area is abhorrent to my consciousness of the sanctity of Science.

The title adopted for this correspondence is attractive. Scottish geologists, including many who are Scottish by choice rather than birth, have paid special attention to the lessons to be learned from chilled edges. The earliest case on record seems to be that of James Hall, who in 1798 announced deductions derived from a study of chilled edges of dykes at Monte Somma. Later, the cult of chilled edges was developed by masters such as Clough and Peach. Harker, however, never fully appreciated their value. This is well seen in a remark he once made in combating criticism I had advanced of his interpretation of the Sgurr of Eigg : " For some of my friends on the Geological Survey this matter of chilled edges seems to have become, in these latter days, a kind of cheap and infallible touch-stone " (*G.M.*, 1914, p. 307). Sallies such as this I have always greatly enjoyed as enlivening debate and at the same time recording opinion.

The letter in your last issue, upon which I wish to comment, is by D. B. McIntyre and Doris L. Reynolds (*G.M.*, 1947, p. 61). It begins

by quoting a statement from a previous letter by J. E. Richey, F. H. Stewart, and L. R. Wager (*G.M.*, 1946, p. 293). These three authors had found a marscoite at certain localities, chilled against a granophyre, and had drawn the natural conclusion that the particular marscoite is later than the particular granophyre. With this, McIntyre and Reynolds contrast Harker's well-known claim that the marscoite is earlier than the granophyre. Later in the letter McIntyre confirms some part of the phenomena relied upon by Harker, and points to a granophyre invading a marscoite. It seems probable to me that there are either two granophyres or two marscoites, or perhaps a succession of granophyres and marscoites. At the same time, McIntyre hints at another possible solution. If this is developed in detail, and if by chance it is not found acceptable by Richey, Stewart, and Wager, it would seem that the stage will be set for a profitable discussion.

McIntyre and Reynolds, in their letter, deal concurrently with the Tertiary centre at Slieve Gullion. Reynolds here interprets the margin of a particular dolerite in contact with a granophyre as showing baking following upon chilling. Apparently the same margin has been interpreted by Richey as showing baking without antecedent chilling. I have examined a slice illustrating the difference of opinion, and certainly adopt Reynolds's interpretation. I admit that I may be wrong, and am anxious to consider contrary evidence. Meanwhile I seem to be one of many who are convinced that Reynolds has done good service in returning the dolerites and gabbros of Slieve Gullion to the Tertiary assemblage (1937, 1941), and still better in discovering remarkable metasomatic alteration of adjoining Caledonian granodiorite. The alteration, as she has pointed out, has proceeded preferentially along the external margins of glomero-aggregates of quartz. It certainly seems to me to some extent metasomatic. For instance, a slice I have been shown contains rims which, so far as I can see, locally consist of pure orthoclase developed at the expense of the quartz (and possibly of some adjoining oligoclase). I admit that I am not convinced by Reynolds's argument for solid diffusion (*Q.J.G.S.*, 1941, p. 15), if this means more than that the quartz areas have tended to fill with new material, much as the water areas of vesicles do when they start to become amygdales. Appearances suggest to me transit of a mobile magmatic solution (emanation seems a good name) along cracks. It is well known that granite does crack when quickly heated at ordinary pressures, and this is ascribed to differential expansion of quartz and felspar. Silica has peculiar propensities : up to 573° α-quartz expands at increasing rate ; at 573° it expands suddenly to yield β-quartz ; on further heating β-quartz contracts extremely slowly, until at above 870° C., in the presence of a flux, it begins to pass with marked expansion to tridymite.

May I say that, though I have from time to time described emanation phenomena (*Colonsay Mem.*, 1911, p. 29; *Glen Coe Mem.*, 1915, pp. 112, 164; *Mull Mem.*, 1924, pp. 167, 319), I have nowhere seen a more hopeful field of research in this respect than has been opened by Reynolds's discoveries at Slieve Gullion.

E. B. BAILEY.

19 GREENHILL GARDENS,
EDINBURGH.
18th February, 1947.

AGE RELATIONS OF CERTAIN GRANITES IN SKYE

SIR,—In their letter in the *Geological Magazine* for January–February, 1947, Dr. Doris Reynolds and Mr. McIntyre discuss *inter alia* the relative age of certain rocks in Skye. Their opinion in this particular case seems to be summarized in a statement at the end of the sixth paragraph of their letter which reads as follows: "the Allt Daraich-Sron a'Bhealain sheet of marscoite is seen both to be chilled against the granophyre and to occur as inclusions within it." This statement assumes that the granophyre against which the marscoite is chilled is the same as the granophyre which contains the marscoite inclusions (Harker's spotted granophyre). Dr. Reynolds and Mr. McIntyre give no evidence to justify this assumption. In our view two granophyres of different ages are involved. One line of evidence on which we rely is the chilled contact to which we originally drew attention but it appears that for others such evidence has a different meaning.

The particular problem of the age of these Skye rocks cannot be discussed satisfactorily within the limits of a letter in this journal. We shall present a map and petrological account in due course.

J. E. RICHEY.
F. H. STEWART.
L. R. WAGER.

24th February, 1947.

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An Outline of the Geomorphological Evolution of British Malaya

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I. INTRODUCTION

MUCH has been written about the alluvial tin deposits of Malaya by Wray, Scrivenor, Jones, Cameron, and others, but little has been published concerning the development of the country's drainage system. A complete geological bibliography for Malaya up to 1931 is given in Scrivenor's *The Geology of Malaya* (1931). The purpose of this paper is to record a few ideas developed by the writer during nearly five years of field work before war broke out in South-East Asia. The writer thanks Messrs. J. B. Scrivenor and E. S. Willbourn, who read and commented upon the paper, and the Directorate of Military Survey, War Office, who supplied maps of Malaya.

The Malay Peninsula extends southwards from the Gulf of Martaban, Burma, to Victoria Point, and thence swings south-eastwards to Singapore Island. It consists in three major mountain tracts arranged *en echelon* thus :—

(i) The Burma-Siam boundary ranges in the north.

(ii) The hills extending through the Kra Isthmus almost to Singgora (Songkhla).

(iii) The South Siam-Malaya-Singapore Island ranges in the south.

The geographical axis of British Malaya lies approximately N.W.–S.E. and stretches for almost 700 miles from Perlis to Singapore City. The tectonic grain of the country, however, lies arcuate athwart its geographical elongation, for the mountain coulisses and intermontane troughs of which Malaya is built trend N.N.E.–S.S.W. in North Malaya, about N.–S. in Central Malaya, N.N.W.–S.S.E. farther south, and almost N.W.–S.E. in South Johore and Singapore Island (Text-fig. 1). The structures are thus convex westwards, for Malaya forms the north-western horn of a tectonic arc aligned approximately parallel with the Banda Island Arc, whose magnificent virgation is shown by the structural trend-lines of Sumatra, Java, Borneo, Celebes, and other smaller islands of the Netherlands East Indies.

II. Synopsis of the Stratigraphy and Structure of British Malaya

The area of Malaya is about 52,500 square miles. Granite and other non-volcanic igneous rocks build about 26,000 square miles of it; stratified rocks older than the granite occupy about 17,500 square miles, and alluvium blankets some 8,500 square miles. Younger than the granite are small areas of Tertiary (Miocene ?) sedimentary rocks including sands, clays, boulder beds and coal measures. The pre-granite sedimentary rocks comprise :—

(iv) Triassic Formation : Quartzite-conglomerate, quartzite, grit, shale, chert, phyllite, and schist.

(iii) Permocarboniferous Formation : Limestone, shale, some chert and quartzite, schist, and phyllite.

(ii) Pahang Volcanic Series : Predominantly pyroclastic rocks with some lavas conformably interbedded with both Triassic and Permocarboniferous strata.

(i) The Arenaceous Formation of the Main Range Foothills : Lithologically similar to the Trias. It may be either Trias or older than the adjacent Permocarboniferous rocks (*Ann. Rep.*, 1940, para. 39 ; 1946).

The geological structure is complex. Scrivenor (1923, 1931) has described the tectonic skeleton of Malaya as consisting in sixteen mountain or hill ranges separated by valley troughs, and these ridges can conveniently be grouped as eight coulisses. Two smaller axes form island groups (Text-fig. 1). The numbers of the ranges as given by Scrivenor (*op. cit.*) are quoted in parenthesis after each coulisse. The Peninsular coulisses are (1) the Setul (Nakawn or Lakawn) Range (Range 1) ; (2) the Kedah-Singgora Range and its southerly continuations (Ranges 2 to 6) ; (3) the Gunong Bintang Range (Range 7) ; (4) the Kledang Range (Range 8) ; (5) the Main (Korbu or Riam) Range (Range 9) ; (6) the Gunong Benom Range (Ranges 10–11) ; (7) the Gunong Tahan Range (Ranges 12–13) ; and (8) the East Coast Range (Ranges 14–16). The Pulau Langkawi group (9) in the Straits of Malacca off the west coast of Perlis, and the Pulau Tioman group (10) in the China Sea off the east coast of Pahang are the island axes. Of these ten coulisses, numbers 3, 4, 5, 6, 8, and 10 are composed wholly or predominantly of granite or other igneous rocks, and granite occurs also in coulisses 1 (Permocarboniferous limestone invaded by the Gunong China granite in the north), 2 (predominantly Triassic with granite forming Penang Island, Kedah Peak, and low hills in Province Wellesley and South Kedah), and 9 (Permocarboniferous rocks invaded by granite). Only the Gunong Tahan Range (Trias) appears to contain no important igneous rocks.

Sedimentation of the Malayan arm of the South-East Asian geosyncline began in Carboniferous times and seems to have been completed in the Triassic or possibly in the Rhaetic period. Thereafter, this basin appears to have become dry land, for no traces of younger rocks save Miocene (?) coal measures and the alluvium are found in Malaya. There is little evidence that Hercynian folding occurred, but the thick boulder-conglomerates of the Foothills Formation may have been laid down along ridges formed by earth-movements of about that date (Richardson, 1946).

The orogeny responsible for the building of British Malaya and the igneous activity which accompanied it are generally believed to be of Cenomanian age. There is, however, some evidence of Tertiary granites in Sumatra and it is possible that some of the Malayan granites are also post-Cenomanian. Fitch (*Ann. Rep.*, 1938–1940) has suggested that some of the youngest granitic intrusions in the Kuantan District of East Pahang may be Tertiary, and Scrivenor (in a letter to the writer) has put forward the suggestion that the rhyolites of the East Coast Islands may also be of this age.

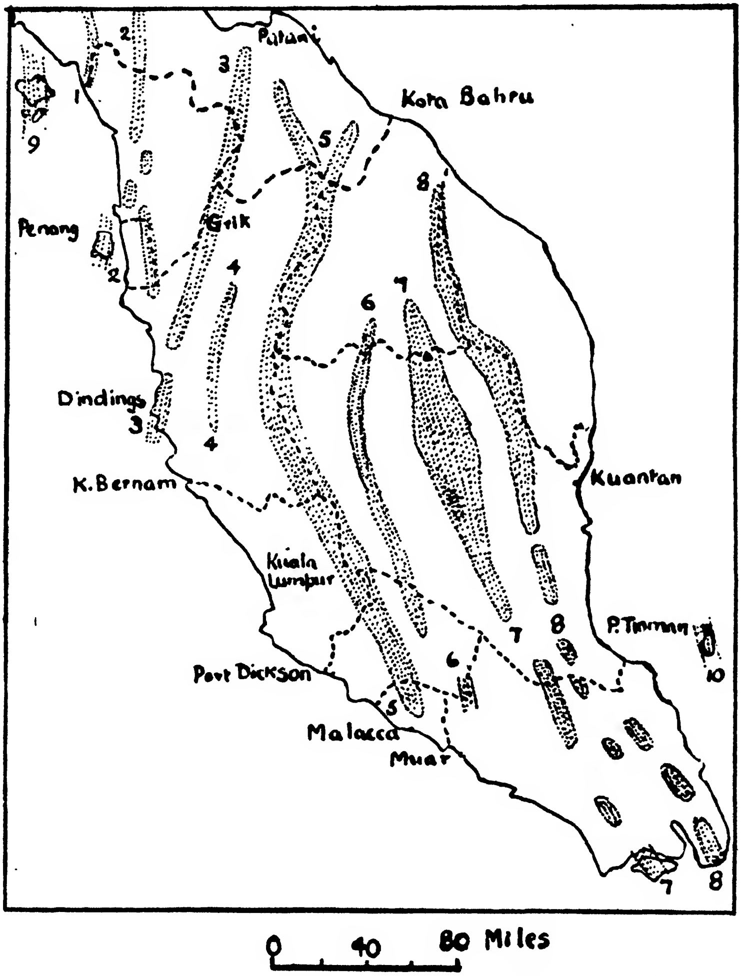
Pressures originating in the China Sea and the Pacific Ocean and operating from east and south-east upon the Malayan geosyncline built up the compressional mountain system of Malaya. Each mountain coulisse is a fold unit in which the strata have been crumpled into series of anticlinoria. The crest lines of individual folds and of groups of folds together are undulating so that they " make and break ", pitching out and rising again either *en echelon* or farther long their strike prolongations. The coulisses themselves are likewise impersistent and undulating, and this characteristic has been of considerable importance in locating watersheds, in controlling the courses of rivers, and in determining the coarse topographic grain of the country.

The land surface, therefore, upon which the drainage system was initiated appeared most probably during late Cretaceous (Cenomanian) times, and it may have suffered some tectonic modification during the Tertiary period. The present-day mountain ranges are the cores of the original fold-humps laid bare by long-continued subaërial erosion. In coulisses 3, 4, 5, 6, and 8 the sedimentary cover has been almost entirely removed down to the granite core. Probably granite everywhere underlies the sedimentary cover of Malaya at depth.

III. The Land Surface: Initiation of the Malayan Drainage System

The primitive Malayan mountain mass probably emerged from the geosynclinal sea as a small whale-backed hump elongated north and south and pitching also in these directions. As the earth-movements achieved their climax and died away, so the dimensions of the new

massif increased and its structure became more complex until a closely compressed system of contorted anticlinoria was produced.



TEXT-FIG. 1.—The Coulisses of British Malaya (after Scrivenor, 1923).
1. Setul (Nakawn); 2. Singgora-Kedah; 3. Gunong Bintang Range; 4. Kledang Range; 5. Main (Riam or Korbu) Range; 6. Gunong Benom Range; 7. Gunong Tahan Range; 8. East Coast Range; 9. Langkawi Islands; 10. Pulau Tioman.

Its major axis was about N.W.–S.E. or N.N.W.–S.S.E.; the transverse axis was about W.N.W.–E.S.E. Malaya at that time was probably an elongate land-mass of considerable altitude with a crenulate or

undulating surface pitching and dying out north and south ; and dropping fairly steeply eastwards to the China Sea and westwards to what is now the Straits of Malacca. There may have been two crest-lines parallel with the major axis, one corresponding roughly with the Main Range and the other with the Gunong Tahan Range. The coulisses extended roughly northwards and southwards as discrete ridges separated by intermontane troughs from the region of the widest transverse diameter. The international boundary of Siam and Malaya is the watershed between rivers flowing north in Siam and south in Malaya and corresponds approximately with the original transverse axis of the landmass. The north-flowing Golok, Kelantan, and Lebir rivers are now exceptions ; originally the States of Kelantan and Trengganu belonged to Siam.

The geomorphological evolution of Malaya up to the end of the Tertiary period consists in three main stages :—

Stage 1.—Development of the primary coarse-grained topography dominated by major north and south flowing longitudinal (strike) consequent rivers occupying the intermontane troughs.

Stage 2.—Development of a finer-grained reticulate topography by the continued down-cutting of the east and west flowing dip-streams tributary to the major longitudinal rivers together with their own north and south flowing strike-subsequent tributaries.

Stage 3.—Development of local drainage units such as radial and semi-radial systems, and elongate networks of rivers in limestone and shale country. This minor drainage has been responsible for etching the topographic minutiae of Malaya.

All the events dating from the beginning of the Pleistocene period up to the present day are grouped together as Stage 4 for the purpose of this brief broad survey.

Stage 4.—Includes the differential warping, sinking, and breaking up of Soendaland (Scrivenor, 1931), modification of the coastal tracts of Malaya, development of the large alluvial plains, formation of tin and gold placers (Scrivenor, 1928), coastal terracing and raised beaches, and other related geomorphological processes of which few details are known in Malaya.

Stage 1.—Almost as soon as rain fell on the new Cretaceous land-surface, consequent streamlets must have begun to flow approximately east and west off the dip-slopes of the mountain humps and north and south in the troughs between them. The location and development of the drainage must have been influenced by :—

(i) The nature (hardness, porosity) of the rocks exposed at the surface during the various stages of denudation.

(ii) Facies changes in the stratigraphical formations.

(iii) The presence of strongly jointed rocks, of soluble formations, such as the Permocarboniferous limestone, and of highly fissile, " directional " rocks, such as schist, phyllite, and phyllitic shale. Little is known of their effects upon the early stages of river development in Malaya, but some facts relating to their subsequent importance are described in a later section.

The main divides between the north and south flowing streams followed the original transverse crest-line of the land mass. But the positions of the local watersheds between adjacent opposed longitudinal streams were controlled by the presence of impersistent individual wrinkles and basins in the intermontane troughs.

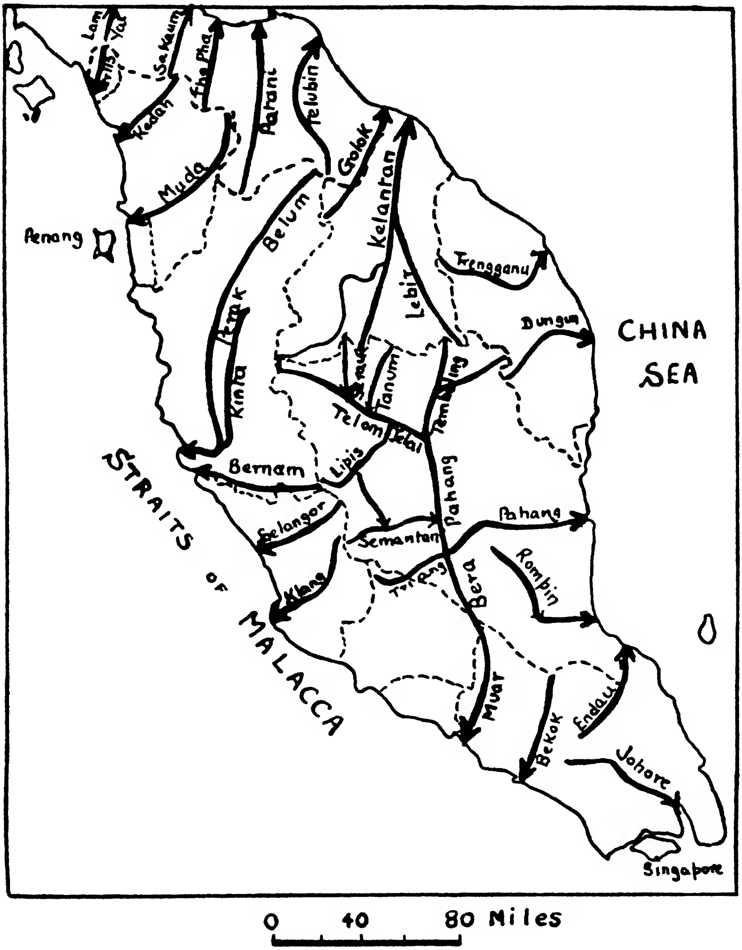
The dip streams were relatively short and swift flowing ; the strike consequents longer and with gentler gradients. The dip consequent systems became canalized into individual systems and cut back into their watersheds which assumed a zigzag form still visible in some localities, such as the Cameron's Highlands District of Pahang. These east and west flowing systems were collected into the main north and south trunks. The streams which now flow directly off the coastal range into the China Sea and the Malacca Straits appear to be the upper parts of rivers once tributary to valleys in the continental shelf now submerged by the shallow seas surrounding Malaya. Considerable river-capture, beheading, and flow-reversal must have taken place during the early stages of river growth ; no details, however, have yet been worked out.

Topographic maps of Malaya and South Siam show this striking arrangement of the main rivers, valleys, and ridges (Text-fig. 2). These rivers, grouped in opposed pairs flowing north and south respectively in the intermontane troughs, include the Lam Yai (N.) and the Perlis (S.) in the Setul–Singgora-Kedah trough ; the Pha (N.) and the Muda and Krian (S.) in the Singgora-Kedah–Gunong Bintang Range trough ; the Patani and Sai Buri (N.) and the Perak-Belum system (S.) in the Gunong Bintang Range–Main Range (plus Kledang Range) trough ; the Kelantan-Lebir system and the Golok (N.) and parts of the Telom-Jelai Kechil and Tembeling systems (S.), between the Main Range, the Benom Range, and the Gunong Tahan Range. Farther east the primary plan has been modified by what appears to have been an important river capture in the Pahang Valley (Text-fig. 3, 1931).

A broadly spaced skeleton of major north and south flowing rivers was thus produced in the tectonic valleys, and these were served by a reticulum of shorter and steeper east and west flowing dip consequents. The rivers of British Malaya are arranged along the four vanes of an elongate parallelogram (Text-fig. 2).

The primary drainage pattern was coarse grained and reflected

clearly the broad tectonic outlines of Malaya. It led to the etching out of the mountain ridges, the deepening of the tectonic troughs, the



TEXT-FIG. 2.—The major rivers of British Malaya shown schematically. The probable course of the Sungei Pahang debouching into the Straits of Malacca is depicted.

isolating of minor structural units, and the early stages of the unroofing of the Malayan granites. It is unlikely that any portion of the original land-surface survived this period. Indeed, conditions of sub-maturity may already have been attained at the estuaries of the main rivers, and for some distance upstream.

Stage 2.—The primary stage of development passed imperceptibly into the second in which the rivers already formed deepened their channels, eroded farther into their watersheds, and picked out the topography in increasingly greater detail. In addition, north and south subsequent tributaries of the east and west consequent streams became of great importance in dissecting the troughs and coulisse-ridges into smaller elongate units. The Main Range Foothills in North-West Pahang, for example, became subdivided by the Kadjau and Khalid rivers between the Telom and Bisek valleys. The Chegar Perah-Pulai porphyry range is similarly deeply dissected by the Galas in Kelantan and the Chiniau in Pahang. Farther west, the Tempoi-Sua-Kerla system, eroding an area of amphibole-schists, phyllites, quartz- and mica-schists, intensified the trough which separates the quartzites and conglomerates of the Main Range Foothills from the granite mountains of the Main Range proper. The south-flowing Ingsor, a tributary of the Serau, with its numerous obsequent dip tributaries, has carved a valley in Permocarboniferous shales and pyroclasts near their junction with the Arenaceous Formation of the Main Range Foothills (Text-fig. 3).

This secondary stage of river growth thus caused considerable refinement and increasing intricacy of the topographic grain of the country. The topography became more or less mature during this period.

Stage 3.—A few examples will illustrate the fine-grained topographic details etched out by the minor river systems.

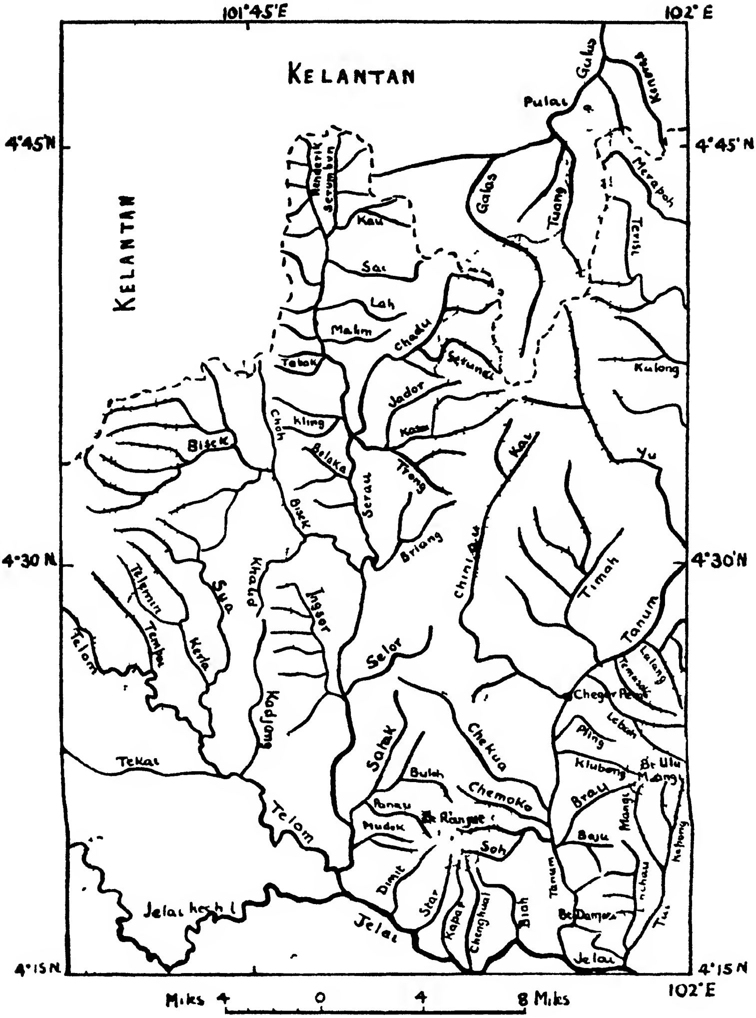
(i) Radial drainage of the Bukit Ranjut syenite dome, Pahang. The dome lies on the Gunong Benom Range coulisse between the Serau, Satak, Tanum, and Jelai rivers which isolated the main hill mass. A large number of relatively small streams then developed on the dome and formed an almost perfect radial system (Text-fig. 3).

(ii) Radial drainage off the Bukit Ulu Mangi granite, Pahang. The tributaries flow out into the Tanum, Kechau, and Jelai rivers.

(iii) Radial drainage off the Bukit Damar granite, Pahang. In examples (ii) and (iii), the headwaters of the radial streams have cut deeply into the granite masses ; the main tributaries, however, flow mostly in sedimentary rocks (Text-fig. 3).

(iv) Rectangular drainage pattern in massively jointed rhyolite tuff in the Serumbun-Henderik-Serau basin, Pahang (Text-fig. 3).

(v) The isolation of the limestone hills between Chegar Perah, Merapoh, and Pulai (Text-fig. 4). Erosion was controlled by the joint pattern in the limestone and by the adjacency of limestone, tuff, and shale. Longitudinal consequent streams flowed along the contact of limestone with shale and tuff. The shale and tuff layers became



TEXT-FIG 3—Geological sketch-map of North-West Pahang (Sheets 2 N 8 and 2 N/12) showing the main rivers schematically Note the radial drainage from the Bukit Ranjut syenite and from the Bukit Ulu Mangi and Bukit Damar granites, rectilinear drainage of the Henderik-Serumbum-Serau system in tuff country, and closely spaced dip streams from the Main Range granite.

Permocarboniferous Formation

Arenaceous Formation of Main Range Foothills

Intrusive Igneous Rocks.

(*N.B.*—The geology of Kelantan is not shown)

more deeply eroded and the limestone belts, left as relatively high standing tracts, became dissected along joint lines generally trending east and west. Much of the drainage in the limestone country is subterranean.

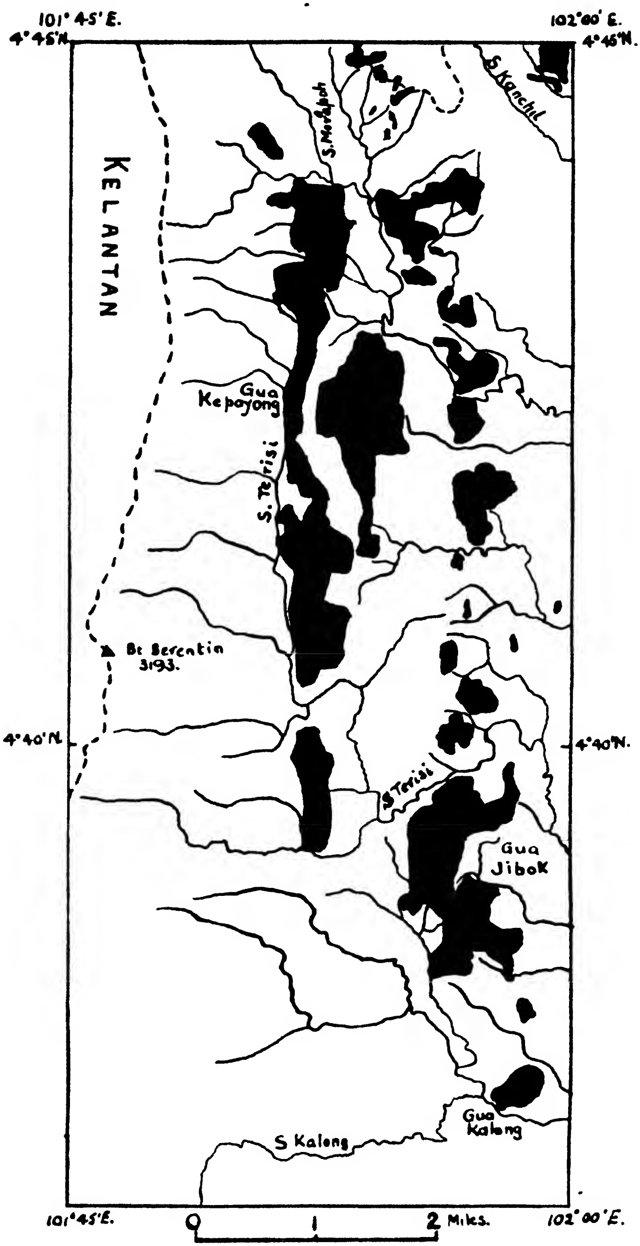
A few examples illustrating the later influence of lithology and jointing on river development include :—

(i) The location in drainage channels occupying enlarged joint planes in limestone of relatively rich pay-shoots of gold in placers at Foo Brothers Hydraulic Gold Mine, Sungei Timah, Pahang.

(ii) The accumulation in solution troughs in limestone of residual gold deposits containing also scheelite and galena derived from mineralized quartz veins at the Tui Gold Mine, Padang Tungku, Pahang.

(iii) The characteristic " trough and pinnacle " topography found in the limestone bottoms of hundreds of mines in Malaya (Scrivenor, 1928, 1931) is the direct result of solution along well developed joint systems. The troughs are commonly as much as 70 feet deep, and they may exceed 100 feet. Much of the deep alluvium in Perak ($>$ 250 feet) lies in such troughs which extend downwards well below the average level of the valley rock-floor, and it is probable that these trough systems have considerably influenced the location of rich pay-streaks in tin placers. The richest tin deposits tend to occur in these bottoms, and this fact leads to considerable losses of tin recovery during dredging operations, for the scraper buckets can seldom reach into these relatively narrow crevices.

(iv) The genesis of the limestone hills of the Kinta Valley and other parts of Malaya has occasioned considerable controversy. Scrivenor has ascribed the striking steep-walled, polygonal shape of the Kinta limestone hills to the effects of multiple faulting and has published a diagram of the faulting systems thought to have been responsible (1913). The writer has mapped the limestone hills along the railway line in the Merapoh area of Pahang on the scale of 2 inches to a mile (Text-fig. 4). They are similar in shape to those of the Kinta valley, but there is no reason to believe that they have been produced by the extensive faulting of a limestone massif. The trend of the country around Merapoh is approximately north and south and the strata have an average dip of some 70° east. Several lenticular bands of limestone, each in turn dying out north and south, are separated by belts of shale, phyllite, and tuff. Around Merapoh the limestone hills are essentially erosional relics, left isolated by the more rapid removal of the intervening bands of argillites and tuffs. The largest of them is Gua Kepayong, about 4½ miles long in the Terisi valley. It is suggested that the limestone hills of the Sungei Siput, Kinta, and Batang Padang Districts in Perak, and those of Kedah, Perlis, Kelantan,



TEXT-FIG. 4.—Group of limestone hills (solid black) and rectangular pattern of rivers. Merapoh area (Sheet 2 N/8), North-West Pahang.

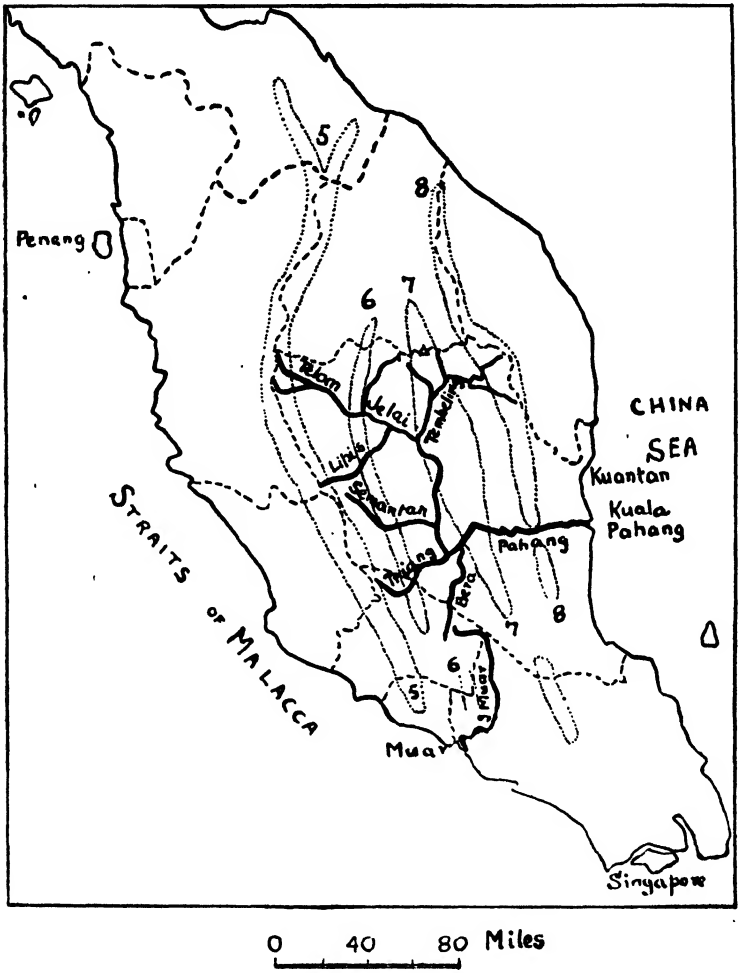
and East Pahang, have all been formed largely by normal denudation controlled by joint and bedding plane patterns. It is worthy of note that dry tributary valleys of the Mae Khlaung Kwae Yai between Chung Kai, Kan Buri (Kanchana Buri), and Tha Makan, some 70 miles west-north-west of Bangkok, Siam, have a reticulate pattern, approximately N.W.-S.E., N.E.-S.W., and E.-W., controlled by strong jointing in massive crystalline limestone. (Observations of the writer whilst a prisoner of war in Siam.)

(v) Jointing in limestone has largely controlled the patterns of caves, potholes, and chasms in the limestone hills of Malaya. Examples include the Batu Caves near Kuala Lumpur, Selangor, where herring-bone patterns are found, Gua Chadu, the Kota Glanggi group, and many others in Pahang, the Temple caves around Ipoh, Perak, and the caves containing rich tin placers around Pelarit and Kaki Bukit in the Setul (Nakawn) Range, Perlis.

Scrivenor (1928, 1931) has discussed the alluvial deposits of Malaya particularly in relation to tin placers and has made some suggestions regarding river history during the Pleistocene and Recent periods. The present writer offers a few ideas ancillary to those put forward by Scrivenor.

Stage 4.—Malaya is almost entirely surrounded by alluvial plains extending from the coasts inland for many miles. The western plains average some 20 miles in width and reach a maximum of about 40 miles in the lower courses of the Bernam and Perak rivers. The greatest width for the eastern plains is in the Pekan District of East Pahang, where the alluvium extends inland for some 20 miles. The plains do not represent a widespread peneplanation of the coastal tracts of Malaya. They are, on the contrary, flat-topped, flood-plains whose surfaces have but a gentle gradient, formed by extensive aggradation of the outermost tracts of the old Malayan landmass largely in the Pleistocene period. The depth of the western alluvium is about 30 feet around Chenderiang and Kampar along the western margin of the Main Range granite ; some 80 to 100 feet around Ipoh, 150 feet to more than 250 feet in the Kampong Gajah and Degong Road areas of the Telok Anson District (*N.B.*—Some of the deepest alluvium here lies in solution troughs in limestone, but much of it is bottomed by granite, phyllite, and quartzite), 365 feet at Sitiawan (bottomed on phyllite), and about 450 feet around Kuala Perak and Kuala Bernam (bottomed on quartzite and shale). Large tracts of alluvium thus lie well below modern sea-level. A boring on Westenholz Estate in the Bernam valley was begun some 50 feet above sea-level. It passed through some 450 feet of alluvium of which about 400 feet lie below sea-level. The depths quoted show that the average gradient of the

rock-floor of the plains between the Main Range and the west coast, a distance of some 40 miles, is about 10 feet per mile, much steeper



TEXT-FIG. 5.—The Sungei Pahang Drainage System, Malaya.
Some of the coulisses are also shown. The Sungei Pahang probably drained originally into the Straits of Malacca via the Sungei Bera and Sungei Muar.

than is usual for a normal peneplain. By contrast, the average gradient of the Jelai-Pahang river-bed between Kuala Lipis and Kuala Pahang on the China Sea coast is about 0·9 feet per mile (the altitude decreases

from *circa* 220 feet at Kuala Lipis to sea-level at Kuala Pahang in about 250 miles). There is no evidence that the suballuvial floor in Perak is a tilted peneplain. The development of the coastal regions, comprising ever-deepening of the valleys and the accumulation in them of thick alluvium, was presumably controlled by eustatic changes in sea-level dependent upon the duration of the Ice Age. Deep channels could have been eroded (as also in Australasia), whilst the local sea-level was lower than normal, and thick, extensive deposits of alluvium might well have been accumulated as the sea returned to its normal level. A few teeth of *Elephas namadicus* and *Elephas antiquus* dredged from tin-bearing alluvium around Malim Nawar and Chemor, Perak, suggest that its age there is about 20,000 to 30,000 years.

Probable River-capture of the Sungei Pahang.

The Sungei Pahang (Text-figs. 2 and 5) is formed by the coalescence of the Telom-Jelai system and the Sungei Tembeling. The main trunk of the Telom-Jelai flows approximately east-south-east as far as Kuala Tembeling where the Sungei Tembeling joins it ; thence, the combined rivers (now named the Sungei Pahang) sweep abruptly southwards as far as Kuala Triang. Thereafter, the course again becomes approximately eastwards to the China Sea near Pekan. The course of the whole river forms thus a large zigzag. The Tembeling, the southerly stretch of the Pahang, Tasek Bera, Sungei Bera, and the Sungei Muar south of K. Menunggol, all lie in about the same north and south line. Only the Sungei Bera flows northwards ; the others run south. The Bera is a small swampy stream occupying only part of a broad shallow valley. Scrivenor (1931) has suggested that the Pahang originally flowed southwards from the Tembeling to the Straits of Malacca at Muar on the west coast ; that its headwaters were captured by the precursor of the east-flowing branch of the modern Pahang (i.e. between Kuala Triang and Kuala Pahang) with the result that the combined Tembeling and Telom-Jelai systems were all made to discharge into the China Sea. Later, the flow of part of the lower course of the old Pahang became reversed and this is now the Sungei Bera. The original Pahang as defined above would fit exactly into the primary river pattern (Text-fig. 2) outlined in this paper. The dying down southwards of the coulisse ridges in Central Pahang might well explain why an east-flowing dip-stream was able to erode back into its head sufficiently to effect the capture of the larger south-flowing longitudinal consequent river. The coulisses make again as low hill ridges south of the Sungei Pahang and there is little really high land in South-East Pahang except around Gunong Lesong, 2,142 feet, and Gunong Besar, 3,403 feet.

Evidence of Inland Terracing : The Terraces of the Ulu Telom and Ulu Bertam, Cameron's Highlands District, Pahang.

A feature characteristic of nearly all the rivers of North-West Pahang studied by the writer is their incision into their flood-plains to depths of between 5 and 10 feet, and sometimes even deeper. Such rejuvenational corrosion may be related to fluctuations in sea-level or it may be the result of developmental changes related to those described below.

Two or three gravel covered river terraces lie above the flood-plain of the Sungei Bertam at Tanah Rata and Brinchang, Cameron's Highlands, at elevations of about 4,500 feet to 4,600 feet. Above them the granite hill-spurs rise stepwise, relatively steep slopes alternating with flat platforms, up to altitudes of between 5,000 feet and 5,500 feet. Valley spurs and ridges in schist and granite country are similarly platformed lower down the valley between Gunong Terbakar, Lubok Tamang, and Renglet, particularly on the inner curve of a large slip-off slope. In the Blue Valley Tea Garden, Ulu Telom, four or five gravel-capped terraces lie between 4,500 feet and 4,700 feet. Above them, again, comes a flight of flat rock-platforms in granite extending up to some 6,000 feet. These all appear to be developmental features of the Ulu Pahang drainage system.

Longitudinal profiles of some forty rivers in North-West Pahang plotted by the writer (Mal. Geol. Surv. Memoir for Sheets 2 N/8 and 2 N/12, not yet published) show that the river courses consist in alternations of steep sections with rapids and waterfalls, and maturely graded stretches of low gradient and gentle flow. These alternations lie particularly between 5,000 feet and 500 feet. The changes of gradient, many of which appear to be normal nick-points, are most common around 2,500, 2,000, 1,700, 1,200, 1,000, and 750 feet ; there are others between 750 feet and 250 feet. Below 350 feet the rivers, in general, maintain fairly well graded courses.

From these few data the writer suggests no more than that regional correlations of the various stages of river development in Malaya may prove practicable when sufficient evidence has been collected.

A few suggestions for research into the geomorphology of Malaya are appended :—

1. Investigation of the alluvial tracts (recommended on economic grounds by Sir L. L. Fermor in his 1939 *Report upon the Mining Industry of Malaya*) in order to determine :—

(*a*) The age and characteristics of the various gravels.

(*b*) Their relationship to the formation of gold and tin placers.

(*c*) Iso-pachytes of the sub-alluvial rock-floor with the object of discovering whether or not buried terraces and old drainage lines

exist below the alluvium. This study might have an important bearing upon the location of payshoots in the placers.

2. Investigation of the longitudinal profiles of rivers in order to attempt a correlation of the numerous changes of gradient which appear to be nick-points, with terraced and bevelled spurs.

3. To map the upland terraces and attempt to correlate them. Terraces occur in the Sungei Tembeling (information communicated to the writer by M. W. F. Tweedie, Raffles Museum, Singapore), at Cameron's Highlands, Pahang, in Southern Johore and Singapore Island. It is probable that they are more widely developed than is at present known.

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The Mode of Emplacement of the Post-Karagwe-Ankolean Granite of South-West Uganda

By Basil Charles King

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Introduction

THE Post-Karagwe-Ankolean Granite occupies very extensive areas in South-Western Uganda and has been emplaced within two systems of sedimentary rocks. These, in order of age, are known as the Toro System and the Karagwe-Ankolean System. In their structural relations towards the granite, the two systems show striking differences one from the other, a feature which provides interesting evidence relating to the " granite problem " on a regional scale and, in addition, throws light on certain aspects of Pre-Cambrian stratigraphy.

Considerable areas of South-West Uganda have been the subject of detailed field-work extending over many years by members of the Geological Survey, especially by A. D. Combe (1932, etc.), while important contributions have also been made by W. C. Simmons (1932), C. B. Bisset (1939), H. J. R. Way (1936 and 1937), R. O. Roberts (1940 and 1942), and the present writer (King, 1941). Preliminary studies of the petrology of the granites have been published (Groves, 1932 ; Simmons, 1939 ; and King, 1939).

It should be observed that while the general stratigraphical characters of the Karagwe-Ankolean System have long been appreciated it was only comparatively recently that various groups of rocks of unrelated age, such as the Igara Schists, Toro Quartzites, and others, at first suspected as being metamorphosed Karagwe-Ankolean deposits, were placed by Combe into one system, which he has called the Toro System (see also King, 1941). A comparison of the geological map, Text-fig. 1, with the corresponding area on the Provisional Geological Map of Uganda, published in 1940, illustrates this point.

The geological succession, with which the present account is concerned, is as follows :—

Post-Karagwe-Ankolean Granite

KARAGWE-ANKOLEAN SYSTEM

— major unconformity —

TORO SYSTEM

(Base not seen.)

Lithologically the two systems show analogous features : both are largely argillaceous, although in each case an arenaceous facies predominates in certain localities. The two systems show, however, considerable differences in degree of metamorphism of regional type, and while original depositional structures are often readily recognizable

in rocks of the Karagwe-Ankolean System they are rarely seen in the Toro deposits. It is important to observe that, locally, where thermal effects due to granite emplacement have been superimposed, rocks of either system may be metamorphosed to more or less identical rock types. This feature has in places led to uncertainty in mapping and, incidentally, is likely to provide problems difficult of solution in parts of Central Uganda.

In general the Karagwe-Ankolean sediments are responsible for the more elevated parts of the area, notably the Kigezi Highlands and the Buhwezu Plateau, but the Toro quartzites also form mountains and ridges of more limited extent. Low relief is usually found where the underlying rocks are granites or argillaceous members of the Toro System.

The Toro System

Broadly speaking the Toro System forms the sedimentary foundation on which the Karagwe-Ankolean beds were subsequently laid down and into which the post-Karagwe-Ankolean granite was emplaced.

Lithology

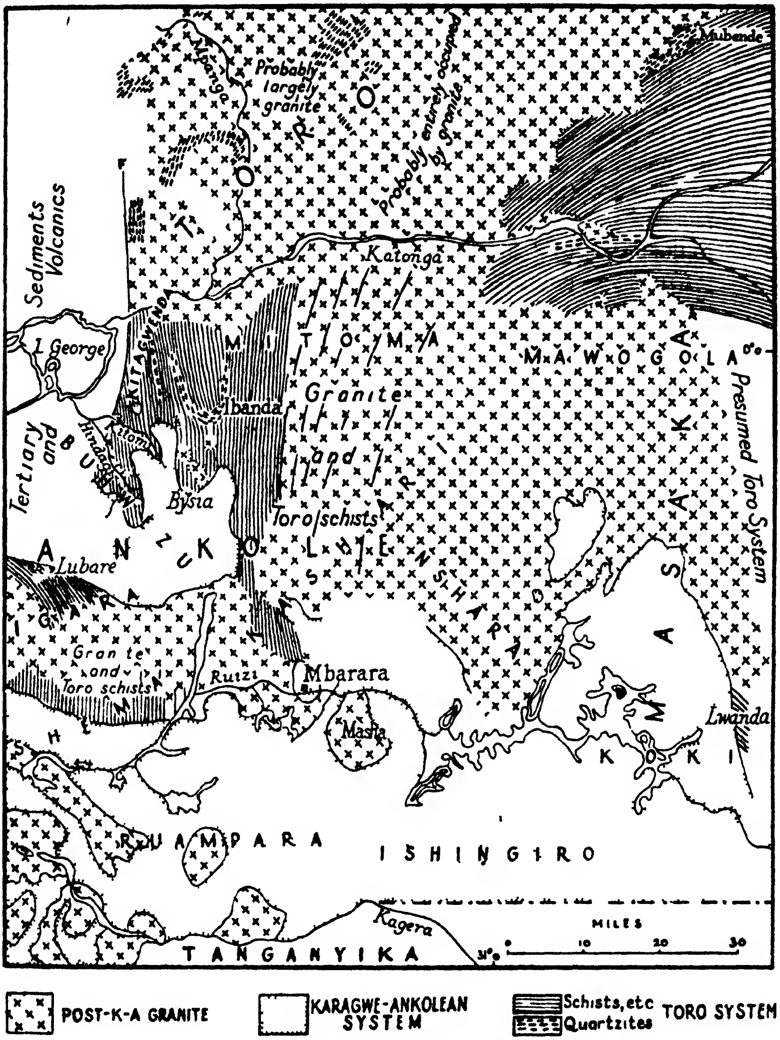
(1) *Quartzites.* As long ago as 1932 Combe had recognized that many of the quartzite masses, Ibanda Hill, for instance, are to be distinguished from those of the Karagwe-Ankolean System and relevant descriptions have been published (Combe, 1933, p. 31 ; 1934, p. 21 ; and 1939, pp. 9–13).

The quartzites are always highly metamorphosed rocks and almost invariably show no trace of original bedding features. Occasionally a faint indication of banding can be made out, due to the presence of layers containing a visibly greater proportion of iron ores, etc., whilst in some places the only direct evidence as to the dip of the beds is afforded by rare partings or bands of mica-schists or flaggy micaceous quartzite. Jointing is a usual feature, and, though some of the joint directions are in accord with the strike, the dip rarely coincides with any joint direction.

There appears to be in general a lithological difference between the larger quartzite masses, such as Ibanda and Mubende Hills, and the smaller quartzite ridges. The former are predominantly of a very coarsely crystalline rock, which weathers to a coarse, sugary, friable " sandstone ", whereas the latter are usually finer-grained, flinty-textured quartzites.

The quartzites always form prominent topographic features : the larger masses rise 1,000 feet or more above the prevailing level of the surrounding schists.

(2) *Argillaceous Rocks* form by far the greater part of the system and were described originally under the name Igara Schist Series



TEXT-FIG 1 —Geological Map of Part of South-West Uganda

The map has been compiled from the Provisional Geological Map of Uganda, 1939, with additional information from more recent mapping An attempt has been made to indicate the structure and extent of the Toro System in the area by the use of conventionalized strike-lines, while the probable geology is shown of certain parts of the area about which little information is available Deposits more recent than the Karagwe-Ankolean are not indicated, but are almost entirely confined to Western Toro and the adjoining part of North-Western Ankole Kigezi District is not included on the map, but it consists largely of Karagwe-Ankolean sediments with a general strike of N W -S E

in the Lubare area by Combe (1939, pp. 6–19). Exposures are generally few and poor and the rocks are practically always extremely weathered, so that the nature of the unweathered rock is often a matter of conjecture. Most abundant are reddish or buff, fine-grained, cleaved, or foliated, sericite-quartz and sericite-chlorite-quartz schists. Other types, apparently related to thermal metamorphism by the granite, are coarser-grained muscovite-schists, which weather to a chara.teristic rusty red colour. The unweathered representatives of these rocks have a green colour, due presumably to the presence of chlorite.

Crumpling or puckering of the folia is in places a feature of the schists, but it is thought that this is to be ascribed principally to the effects of granite emplacement.

(3) *Other Rocks.* These include sandy or gritty types, which are of especial interest in that they are sometimes the least metamorphosed rocks of the system. In a number of localities in Mitoma and Kitagwenda such rocks show distinct bedding and original clastic grains of quartz (King, 1942, p. 22). They are in all cases interbanded with the schists.

Structures of the Toro System

As indicated above it is only exceptionally that original depositional structures are observable in rocks of the Toro System. Usually the disposition of the rocks can be ascertained approximately by the orientation of bands of slightly differing composition or by the attitude of quartzite horizons in their relation to the topography. The argillaceous types always show strong cleavage or foliation in a vertical or nearly vertical plane, and it is tolerably certain from such direct evidence as is available that the strikes of the foliation and bedding coincide, while the directions of dip do not greatly depart one from the other.

Of great significance is the relative constancy of strike direction shown by the Toro System over wide areas. In Shema, Buhwezu, and Mitoma this is very nearly N.–S., sometimes a little west of north, while east and south-east of Mubende the strikes are almost E.–W. A gradual swing in the regional strike trend from N.–S. to E.–W. takes place as the system is traced from the southern and western towards the north-eastern part of the area.

Within the system it has proved quite impossible to determine either the order of superposition or the thicknesses of the strata represented in any part of the area. It is certain that the same horizons are repeated many times in directions at right angles to the strike and isoclinal folding has probably affected the argillaceous members of the system. It is likely that some of the nearly parallel quartzites are corre-

sponding limbs of synclinal or anticlinal structures and that the apparently disproportionate size of such quartzite masses as Mubende or Ibanda is due to the tectonic thickening of a quartzite horizon at the crest (or keel) of a pitching anticline (or syncline).

It may be suggested that the major quartzites from Mubende through Toro to Ibanda are found in the same part of the Toro System, but whether upper or lower cannot be determined. The discontinuity of the quartzite outcrops is probably due in part to tectonic lensing, rather than only to depositional variations, as well as, in Toro, to cross-cutting invasion by granite.

THE KARAGWE-ANKOLEAN SYSTEM

Lithology

A detailed account has already been published of South-West Ankole and the adjoining parts of Kigezi where rocks of the Karagwe-Ankolean System form mountainous country rising in places to about 8,000 feet (Combe, 1932, pp. 22–35). Combe states that the system consists of alternating grey, blue, purple, or pink thinly-bedded or unbedded mudstones, thinly-bedded and laminated phyllitic shales and phyllites, together with sandstones and quartzites : the latter occur at intervals from close to the base almost to the top of the system. Combe employs the more persistent quartzites, of which there are six in Kigezi and four in the eastern part of the area, as " marker beds " for the purpose of correlation. A continuous succession of great thickness is found in Eastern Rukiga (Kigezi District).

Bedding planes, as well as cleavage, can often be seen in the phyllites and mudstones, whilst it is not uncommon to find original grains, ripple-marks, current-bedding, and lenses of conglomerate in the arenaceous members of the succession.

Subsequent work by Combe (1941) has revealed identical features in the Karagwe-Ankolean deposits farther to the north in Ruzhumbura, Ruampara, and in the neighbourhood of Mbarara, while westwards towards the borders of Masaka District similar lithological successions have been observed by Bisset (1939) and Way (1936 and 1937).

More recent mapping by Roberts (1940 and 1942) has shown that the Buhwezu Plateau, rising in places to more than 7,000 feet, consists of a predominantly arenaceous facies of the Karagwe-Ankolean, with the following succession [1] :—

		Feet.
(iii) Phyllite Group (with thin quartzites) .		2,000
(ii) Sandstone Group	approx.	4,000
(i) Grit Group (with conglomerate) . .		600

[1] Roberts also includes 150 feet of mudstones and mica-schists at the base of the system, but, since these are only locally developed, they have been omitted from the general succession. See also King, 1942.

Only the uppermost group appears on the south-western part of the plateau where, apparently, it laterally replaces the sandstone group, so that, in the Lubare area, arenaceous rocks are again subordinate and are largely confined to the lower part of the succession (Combe, 1939).

Structures of the Karagwe-Ankolean System

The base of the Karagwe-Ankolean System in Mitoma, Buhwezu, Igara, and Shema is demonstrably an unconformable junction with the Toro System, while at Lwanda in Masaka District an exposure has been found which shows Karagwe-Ankolean beds resting unconformably on rocks which are presumably to be correlated with the Toro System (Simmons, 1932, p. 225). There is ample evidence to show that the earliest deposits of the Karagwe-Ankolean System were laid down on the largely peneplaned surface of the upturned edges of the Toro rocks. Hills and ridges of Toro quartzite projected above the general level of the peneplane, much as the Ibanda and Kijongo quartzites rise above the level of the schists of the Toro System to-day.

On the Buhwezu Plateau the predominantly arenaceous succession lies more or less horizontally, although on a smaller scale more complex structures are to be seen, including minor synclines and anticlines with dips which locally exceed 45°.

In South-West Ankole and Kigezi the Toro System is not found, but the bottom of the Karagwe-Ankolean is always an intrusive contact with the later granite.[1] Over wide areas the limit of granite invasion is always at approximately the same stratigraphical level and the presumption is that this level is at or near the true base of the system. Cross-cutting relations, however, are commonly observed in detailed mapping, while in a few localities the granite invades across the strike on a major scale.

Folding in the Karagwe-Ankolean in the south-western part of the area is everywhere intimately related to and dependent on the mode of emplacement of the post-Karagwe-Ankolean granite (Combe, 1932, pp. 85–6). The sediments occupy more or less tightly squeezed synclinal belts between the granite areas and the strikes are commonly parallel to the granite margins. The steeply outward-dipping concentric ridges of Karagwe-Ankolean deposits, which form the walls of granite "arenas", often relatively flat-bottomed and of approximately circular outline, are conspicuous features of South-West Ankole. In general, progressively higher parts of the succession are encountered with increasing distance from the granite contacts.

[1] Combe has recently suggested that careful search might reveal traces of the Toro System as rafts of schist in the granite arenas.

The Post-Karagwe-Ankolean Granite

The granite will be considered under two headings which broadly delimit those masses which were emplaced largely within the Toro System and those invading the Karagwe-Ankolean System respectively. These divisions, it must be emphasized, are employed solely for purposes of description, since the identity of the typical granite has been established, not only in the field, but also on petrographic and chemical grounds (see Simmons, 1939 ; and King, 1939).

(a) *Granites of Southern Toro and North-Western Ankole Districts*

Detailed mapping in the country immediately to the west of the Buhwezu Plateau reveals that outcrops of granite are, remarkably enough, almost completely confined to the river valleys, while the intervening areas are occupied by Toro schists. Granite is found practically continuously along the courses of the Hindagi and lower Kitomi Rivers and in a few places granite follows the headstreams on to the plateau slopes and invades the lower part of the Karagwe-Ankolean succession. It is reasonably certain that the granite underlies the Toro sediments at no great depth, while the level of erosion of the Hindagi-Kitomi basin and, to some extent, the direction of drainage were controlled by the inclination of the granite surface.

In North-West Mitoma and the Lubare area of Igara, granite occurs intermittently along valley bottoms (Combe, 1939, p. 17 ; and King, 1942), and has often given rise to barriers in the swamps, whilst local elevations of the granite surface penetrate the basal part of the Karagwe-Ankolean, or determine the existence of " hanging basins " such as the Bysia swamp.

The granite varies from even, medium-grained types to coarse-grained porphyritic varieties, while a profusion of gneissose rocks forms the smaller outcrops and the margins of the larger bodies. It is readily apparent from the field relations that the gneisses represent intermediate stages in the process of granitization of the schists (cf. Combe, 1939, p. 9). As the granite is approached, the fine-grained sericite-schists are initially modified to coarser-grained muscovite-schists and these in turn pass into biotite-schists. The transition to gneissose rocks is due to the appearance of granitic material along the schist folia, with the eventual production of a banded gneiss in which the biotite-rich bands are residual sedimentary features that largely preserve the original strike directions of the pre-existing rocks. The occurrence of schlieren of hornblende-schist and gneiss in these marginal migmatites is a common feature. The initial enrichment of the pre-mobilized rocks in biotite and hornblende is in accordance with D. L. Reynolds' demonstration of the existence of an early

Mg-Fe-Ca " front ", which goes ahead of alk-aluminous emanations in the granitization processes (Reynolds, 1943).

In the gorges of the Kitomi River the more arenaceous grits and flaggy schists become more evenly granitized, without conspicuous development of biotite. Thin felspathic bands become progressively more prominent and finally appear to permeate and mobilize the entire rock (King, 1942, p. 25).

Northwards in Toro the quartzites are entirely surrounded by granite, but the presence of occasional thin " shields " of schist against the quartzite is reasonable evidence that such rocks were formerly of greater extent. Westwards into Masaka District, in country with low relief and few exposures, extensive areas of granite with rafts or relics of Toro schists have been recorded (Bisset, 1939, pp. 25–7).

(b) Granites of South-West Ankole and Kigezi Districts

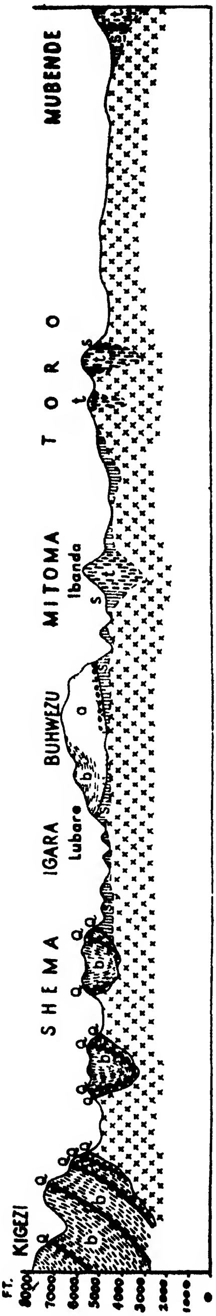
Three types of granite were described by Combe (1932, pp. 47–60) :—

1. Banded and Augen-Biotite-Gneiss ;
2. Coarse-grained porphyritic Biotite-Granite ; and
3. Pegmatitic Muscovite-Granite.

Of these the subordinate pegmatitic granite usually shows sharp junctions against both the invaded Karagwe-Ankolean sediments and the biotite-granite, and is consequently regarded as the latest phase of granite invasion. The normal biotite-granite and the gneissose granite were at first suspected to be of different ages, but Combe demonstrated in the field that the one passes by imperceptible stages into the other, whilst both are evidently later than the sediments. Groves confirmed this gradation petrographically and showed that the two are undoubtedly different phases of the same granite (Groves, 1932).

The gneissose phase occurs principally towards the contact with the sediments near the margins of the granites and the foliation is often parallel to the contact itself, and incidentally to the strikes in the adjoining country rocks, while in certain localities a narrow zone, which was interpreted by Groves as representing a crushed or sheared schistose granite, intervenes between metamorphosed sediments at the contact. These features were regarded by Groves as indicating the existence of powerful shearing forces developed as a result of pressure operating on the granite of the marginal zone.

The present writer suggests, however, from visits to certain of the critical localities and from an examination of relevant rock-sections, that the occurrences show progressive metamorphism and granitization of the country rocks, of which the schistose and gneissose granites are successive stages in the transition. It is significant that Combe states that " in the more severely crushed types " the granite " becomes



a foliated, and often much puckered, quartz-sericite-schist and in some cases resembles certain quartz-sericite-schists which are known to be highly metamorphosed argillaceous rocks of the Karagwe-Ankolean System" (Combe, 1932, p. 55). Combe also contends that the field evidence testifies to assimilation having occurred on a considerable scale. Not only are rafts of metamorphosed sediment of frequent occurrence within the granite area, but certain quartz bodies, although entirely enclosed by granite, appear to be quartzites isolated by the complete assimilation of the adjacent argillaceous rocks of the Karagwe-Ankolean System (op. cit., p. 75).

The Mechanism of Granite Emplacement

The Toro System, characterized by approximately vertical dips and strike directions which are comparatively constant over wide areas, has remained structurally almost unaffected by the very extensive granite invasion to which it was subjected. The emplacement of the granite has been effected by processes of granitization which acted on the sedimentary rocks without significant deflection of the strikes or dips. It seems reasonably certain that, even where most extensively developed, as north and south of the Buhwezu Plateau, the rocks of the Toro System are but a relatively thin veneer overlying granite, which at no great depth is continuous below the entire area. The diagrammatic section, Text-fig. 2, illustrates this conception.

Text-fig. 2.—Diagrammatic Section (not drawn to scale) illustrating the principal structural features of South-West Uganda.

Toro System : s—schists, etc. ; t—quartzites.

Karagwe-Ankolean System : a—sandstones, etc. ; b—shales and phyllites ; Q—quartzites.

Post-Karagwe-Ankolean Granite—crosses.

The quartzites of the system were evidently superior to the argillaceous and intermediate rock types in their resistance to the processes of granitization and the quartzites of Toro appear as relics which were left after the adjacent schists had been largely or completely replaced by granite. It seems probable that, at an earlier stage in the course of denudation, the Toro region passed through the stage at which Mitoma is at present and that further erosion of the Toro System in the latter area will leave only the " roots " or " fangs " of the quartzite masses entirely surrounded by granite.

On the slopes of the Buhwezu Plateau the level of the upper surface of the granite shows remarkable uniformity and is not greatly below and occasionally oversteps the stratigraphical base of the Karagwe-Ankolean System. In South-West Ankole and Kigezi the granite is always at least at and often transgresses above the base of the Karagwe-Ankolean, so that the Toro System, which formerly underlay it, has been entirely engulfed in the course of development of the granite.

While locally, as in Ruzhumbura (North Kigezi), Karagwe-Ankolean rocks have been partially replaced by granite, it is more usual to find that the latter has arched or domed up and pushed aside the beds of the Karagwe-Ankolean System. The mechanism of granite emplacement into this system is therefore in striking contrast to that in the Toro System farther to the north. In its relation to the Toro System the granite behaves as if it were formed in situ and replaced large volumes which were formerly occupied by sediments, whilst towards the Karagwe-Ankolean System the granite has, in most places, the character of an eruptive body, which rose to its present position by upward and outward displacements of the country rocks (cf. Bisset, 1939, p. 27).

An interesting analogy is provided by one of the earlier writers on the nature of granites, A. H. Green (quoted from Read, 1943, p. 71), who stated that " granite occurs under three forms. Under the first it still retains traces of bedding or is interstratified with undoubtedly bedded rocks ; here there is no doubt that it is an intensely metamorphosed rock. Under the second form granite occurs in amorphous masses which melt away insensibly on all sides into unaltered strata, show no signs of having burst violently through the adjoining beds, but look as if they filled up spaces once occupied by rocks similar to those that surround them.... Under its third form, granite gives proof of having been forcibly intruded into the rocks among which it occurs ".

It is believed that two factors were largely responsible for the " dual aspect " of granite invasion in South-West Uganda, namely the structural disposition of the invaded systems at the time when granite emplacement occurred and the thermal conditions which obtained at the different crustal levels. Sederholm (1936) demonstrated that

the form and contact relations of granite bodies were connected with the depth at which they were emplaced and, more recently, the same theme has been further elaborated by Kropotkin (1940). The latter contends that the formation of granites is related to thermal conditions found in the cores and roots of belts of orogeny by the fusion or selective fusion of the sial. Apart from effusives he recognizes three main magmatic products :—

1. Allochthonous masses, occurring at depths of from 0 to 5 km. and associated with upward movement ; the forms are stocks, dykes, sills, etc., which are characterized by small size and often concordant contacts, with little or no assimilation or contact metamorphism.
2. Autochthonous masses, occurring at depths of from 2 to 10 km. in the zone of maximum compression ; the forms are batholiths, which are characterized by large size, cross-cutting contacts, wide development of assimilation and, generally, much thermal metamorphism.
3. Migmatites and gneisses, occurring below 10 km. and associated with downward movement ; these are characterized by irregular form, concordant and disconcordant contacts, often diffuse, and with gradual transition to metamorphosed rocks of the " katazone ".

In its relation to the Karagwe-Ankolean the granite shows features which, according to locality, resemble those of groups 1 and 2 above, while the relations with the Toro System are commonly those of group 3. It seems that the base of the Karagwe-Ankolean System acted as a " barrier " to the geothermal conditions, characterized by regional granitization, which readily pervaded the vertically disposed Toro System. At the higher crustal levels the magma, produced by granitization of the Toro System, was thrust upwards, probably as a result both of the volume increase involved in the process of granitization and of regional lateral pressure within the orogenic zone (cf. Backlund, 1946, p. 115). The effect of the structural contrast between the two systems was to telescope into a relatively limited crustal depth zone the transition between the ultra-metamorphic (syntectic) and the eruptive (rheomorphic) " aspects " of the Post-Karagwe-Ankolean Granite.

Acknowledgment

The writer is greatly indebted to Mr. A. D. Combe, of the Geological Survey of Uganda, for his comments and helpful suggestions, and regrets that, within the limits of the present short account, it has been impracticable always to refer in detail to the extensive literature, both published and unpublished, for which Mr. Combe was very largely responsible, and on which the writer has freely drawn.

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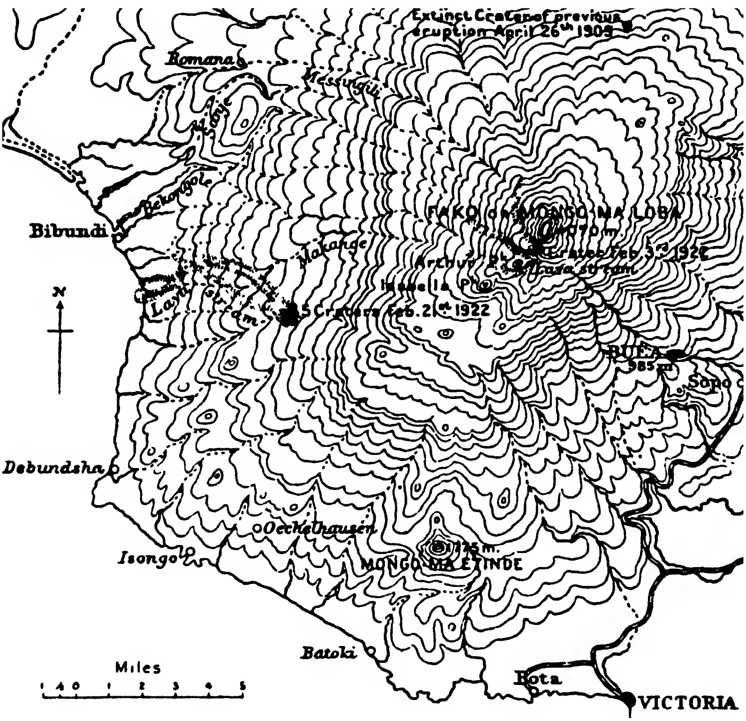
An Olivine-basalt from Bibundi, British Cameroons, West Africa

By GERALD M. PART

THE Geology Department of Reading University recently received four specimens of lava of the 1922 eruption at Bibundi, British Cameroons, collected in 1945 by Mr. E. D. Bumpus, a former student of the University, now of the Nigerian Agricultural Service.

The eruption, which has been described by the District Officer,



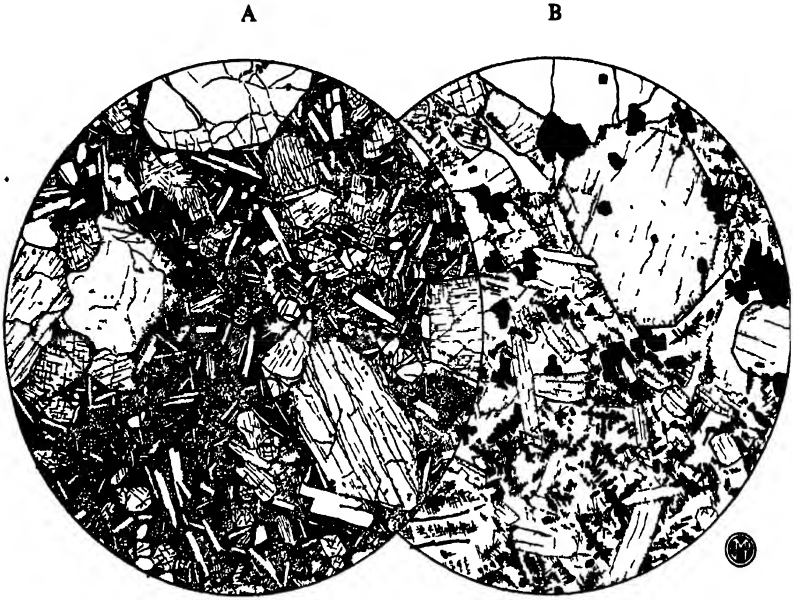
TEXT-FIG. 1.—Map of Cameroons Mountain, British Cameroons. (Reproduced from Capt. Ruxton's paper, *Geograph. Journ.*, lx (1922).)

Capt. F. H. Ruxton, from official and eye-witness reports (1),[1] lasted from early February until late in March, 1922, and was accompanied by earthquake shocks sufficiently severe to be recorded in Europe. The lava flowed from a group of parasitic cones on the south-west flank

[1] Numbers in parentheses refer to references at end of paper.

of Mount Faco at about 4,150 feet (Map, Text-fig. 1) and about four miles from Bibundi beach, near which the flow eventually reached the sea; no activity seems to have been associated with the old 1909 crater on the northern side of the mountain.

No. 1 comes from the lip of an extinct crater at the summit (at



TEXT-FIG. 2.—(A) Olivine-basalt (No. 2), Bibundi, British Cameroons (× 16) (B) Same, showing skeletal magnetite in glassy base (× 100).

13,350 feet). It is a much decomposed basaltic tuff with lapillae averaging rather less than a centimetre in size, now largely reduced to a soft red lateritic material, though still showing some black glassy cores in some of the fragments, and containing numerous black crystals of titan-augite up to 4 mm.

The remainder all come from the recent 1922 eruption and are fresh black aphanitic vesicular rocks with visible phenocrysts of olivine and pyroxene (2–4 mm.). Nos. 2 and 3, from " crack 4 feet down in lava " and " surface of flow " respectively, are essentially similar in character, showing under the microscope phenocrysts of fresh olivine and clove-brown titan-augite (1–4 mm.) which make up nearly half the rock, pyroxene predominating. The fine vesicular base consists of similar pyroxene, plagioclase, magnetite, and variable amounts of coffee-

brown glass (Text-fig. 2A). No. 4, " surface of flow," is more obviously glassy, with a ropy surface, and in section shows phenocrysts of similar olivine and titan-augite in a base of clear brownish-yellow glass which contains numerous smaller crystals and microlites of pyroxene, felspar, magnetite, and occasional olivine.

Minerals.—Olivine—Occurs mainly as phenocrysts, partly idiomorphic, but most crystals show more or less rounding and " embayment " except in No. 4 where it is predominantly well formed. The mineral is quite fresh with R.I.[1] α 1·663 γ 1·698 ·—$Fe_{14}Fa_{86}$ (2).

Titan-augite—In phenocrysts of similar size to those of olivine, of excellent shape, somewhat elongated //c and slightly flattened //100. Twinning (//100) is rare, but glomero-porphyritic aggregates are common, especially among the smaller crystals. The colour is a pale clove-brown with slight greenish tinge in the cores and deeper " violet " in the marginal zones. R.I. is α 1·697 γ 1·723. Extinction varies Z/c 53° (red light) – 50° (blue light) for the cores with slightly lower values, 51 – 48°, for the outer skin. 2V(+) varies from 59° (core) to 55° (outer skin). The pyroxene of the ground-mass is idiomorphic, averaging about 0·15 mm., similar optically to that of the phenocrysts, but having the slightly deeper " violet " colour and lower extinction found in the marginal zones of these. Hour-glass structure is common and well-developed. Feathery skeletal growths occur in the glassy matrix of No. 4.

Felspar—This is mostly a medium labradorite, occurring as laths in the ground-mass in all sizes up to 0·5 mm. Measurements of extinction angles, R.I. (α 1·563 γ 1·569) and 2V (+) 81° indicate that most of the interior of the crystals has a composition about An_{50}, but values as high as An_{65} have been found and the larger crystals show a steady progressive change towards their margins to a composition of about An_{50} with an outer skin having low extinction and R.I. 1·550 (approx.), say, An_{30}.

Magnetite—Abundant in all sections and occurring in two forms—(*a*) in well-formed octahedra of all sizes up to 0·1 mm. in the more crystalline parts of the ground-mass of Nos. 2 and 3 ; and (*b*) as an acicular and skeletal network in the brown glassy portions (Text-fig. 2B). In No. 4 the glass is mainly clear and the bulk of the magnetite occurs as crystals or irregular crystal-groups. It is almost certainly titaniferous.

The glassy base of No. 4 has R.I. 1·601.

A chemical analysis of No. 2 by Mr. W. H. Herdsman shows the following composition (A) :—

[1] All figures for R.I. are given $\pm 0 \cdot 002$.

	A.	B.	C.
SiO_2 . . .	43·27	42·14	43·12
TiO_2 . . .	2·86	4·90	3·45
Al_2O_3 . . .	14·16	14·95	12·94
Fe_2O_3 . . .	2·91	2·90	1·98
FeO . . .	10·22	9·71	9·52
MnO . . .	0·32	—	0·26
CaO . . .	10·82	10·32	12·62
MgO . . .	10·14	9·47	8·09
Na_2O . . .	2·84	3·27	2·65
K_2O . . .	1·28	1·80	1·42
P_2O_5 . . .	0·66	—	0·44
CO_2 . . .	nil	—	1·60
H_2O (−) . .	0·20	0·28	0·32
H_2O (+) . .	0·06		1·36
	99·74	99·74	99·77

or	7·6	
ab	9 7	
an	19·4	
ne	7·8	
di	24·2	III. 6.3.4.
ol	18·7	Limburgose
mt	5·1	
il	5·4	
ap	1·5	

A.—Olivine-basalt, Bibundi, British Cameroons (No. 2). (W. H. Herdsman.)

B.—Olivine-basalt, between the Gap and Horseshoe Bay, Victoria Land. (Prior.)

C.—Limburgite-basalt, dyke, Quail I. Porto Praia, S. Tiago, C. Verde Is. (C.D. 4713–" Beagle " Coll.) (W. H. Herdsman.)

The other analyses quoted for comparison differ chiefly in their higher titanium content. The type is well represented in the Cape Verde Archipelago (" Quest " Collection, British Museum (Nat. Hist.), A.28) (3). CD4713 was originally described by Harker (4), but the analysis is a new one not previously published.

I gratefully acknowledge a grant from the University of Reading Grants Committee to meet the cost of the chemical analysis quoted above.

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The Stratigraphy of the Albian Beds at Leighton Buzzard

By C. W. WRIGHT and E. V. WRIGHT

INTRODUCTION

THE unusually interesting Albian beds exposed in the neighbourhood of Leighton Buzzard in Bedfordshire have been the subject of descriptive papers by Lamplugh and Walker (1903), Kitchin and Pringle (1920), and Lamplugh (1922), as well as a number of short notes and excursion reports. These papers give details of the stratigraphy of the Leighton Sands, the overlying Gault, and the extraordinary beds which occur in between them round Shenley Hill. Many of the ammonites from the "*regularis* nodules" of Billington Crossing, south of the town, were described by Spath (1922–1943). He also referred, in the same work, to a number of Upper Albian forms from the Nodule Bed at the base of the Upper Gault on Shenley Hill. Our own collecting, carried out intermittently since 1937, has produced many new records, including several new species, and recent work has enabled us to amplify the stratigraphical picture given by the authors mentioned above. The present paper deals only with the stratigraphy but we hope that it will be followed by papers on several elements of the fauna.

Our thanks are due to the owners of the various pits and to all those with whom we have discussed the stratigraphical and palaeontological questions of these beds, but especially to Mr. R. Casey, Mr. R. V. Melville, Dr. K. P. Oakley, and Dr. L. F. Spath.

STRATIGRAPHY

Shenley Hill.—Of the pits round the lower slopes of Shenley Hill, only Munday's Hill Pit (adjacent to the former 21-Acre Pit) now yields good examples of the limestone lenticles. 21-Acre Pit itself is now filled up with waste material, chiefly from Munday's Hill, while Harris's Pit, which until recently produced lenticles, was largely buried just before the war by slipped masses of Gault clay.

Limestone lenticles are not infrequent in the south-west corner of Munday's Hill Pit. At this point the ferruginous conglomeratic bed above the sands thickens to $2\frac{1}{2}$ feet and includes limestone lenticles up to 18 inches thick. Moreover, above this bed and below the dark grey clays of the Lower Gault there are patches of clays not represented elsewhere in the district. The lower part of these, up to 4 feet thick, is dull red to purple in colour and contains throughout decalcified valves of the cirripedes *Cretiscalpellum unguis* (J. de C. Sowerby)

and *Pycnolepas rigida* (J. de C. Sowerby). At the base of the red clay there is a thin band of light brown and red clay containing closely packed valves of the two species of cirripedes and ossicles of *Isocrinus* sp., which evidently grew in abundance on the eroded surface of the carstone immediately underneath. It was evidently from this band that Toombs (1935) collected the hundreds of cirripede valves referred to by Withers (1934, p. 48, 353).

Above the red clay is pale grey, sometimes greenish grey, clay, seen to a thickness of about 3 feet, in which we have noted the following fossils, mostly crushed :—

Neohibolites sp.
Plicatula sp.
Spondylus cf. *gibbosus* d'Orbigny.
Velata sp.
Oxytoma pectinatum (J. de C. Sow.).
" *Terebratula* " *capillata* d'Archiac.
" *Terebratula* " *dutempleana* d'Orbigny.
Cidaris sp.
Cretiscalpellum unguis (J. de C. Sow.).
Pycnolepas rigida (J. de C. Sow.).

All these species are known from the limestone lenticles below and, though belemnites are rare in the limestone, we think that the fauna of the pale grey clay is closer to that of the limestone than to that of the dark grey *dentatus* Zone clays above.

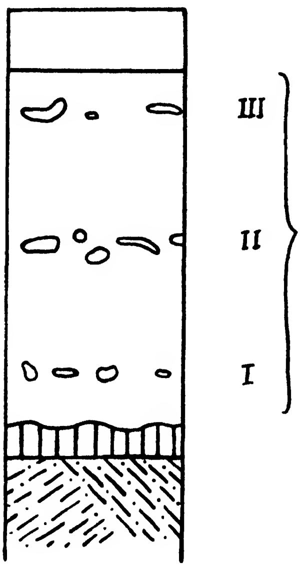
These red and pale grey clays are probably only the very fragmentary remains of the original succession. The disappearance of other beds, and of these in most exposures, appears to be due not only to penecontemporaneous erosion but also to some extent to hill creep. The hard upper surface of the carstone conglomeratic bed is well polished and, apparently, the mantle of clay on Shenley Hill has slid downwards and outwards (and is perhaps still sliding) leaving only occasional pockets of the lowest clays preserved in place.

In the absence of ammonites it is difficult to decide the precise age of these clays and they may in fact belong to any horizon between " Shenley Limestone " times (middle or upper *Leymeriella tardefurcata* Zone) and that of the dark grey clays above (*intermedius* Sub-zone of the *dentatus-spathi* Zone). Whatever may be their exact age they have an extraordinary resemblance to parts of the " *minimus* " Marls (middle and upper A beds) at Speeton.

The dark grey clays on Shenley Hill are not particularly fossiliferous, though *Neohibolites listeri* and *Inoceramus concentricus* are fairly common. Toombs (1935) found ammonites of the *intermedius* Subzone 3 feet above the top of the red clay in his section and we have

a few fragments of *Anahoplites* of the *intermedius* group from the lower part of these clays. It appears, therefore, that the clays of the *dentatus* sub-zone which usually form the base of the true Gault and which are present at Billington Crossing were eroded or that deposition was here suspended until *intermedius* times.

In recent years excavation at Munday's Hill Pit has extended far enough into the hillside to expose several feet, although somewhat



4. Topsoil, with gravel at base containing *orbignyi* subzone ammonites.

3. Gritty and pebbly chocolate, brown, and dark grey clay, with three bands of scattered irregular pebbly phosphatic nodules.

2. Irregular ferruginous conglomerate, sometimes phosphatized.

1 Current bedded sands.

TEXT-FIG. 1.—Generalized section of the upper part of the exposure in Chamberlain Barn Pit.

disturbed, of pale grey clays of the base of the Upper Gault (*orbignyi* sub-zone) as in Harris's Pit. These clays at their base yield abundant black phosphatic nodules with grey coats, many of them casts of ammonites. The commonest forms are species of *Euhoplites* with *E. inornatus* Spath outnumbering the rest. The phosphatic ammonites, however, are found in the subsoil of the lower slopes of Shenley Hill, even as far west as Chamberlain Barn Pit, where there is a thin layer of gravel containing many specimens.

Spath (1922–43, p. 271, 747) records a fragment of *Euhoplites loricatus* Spath in our collection from the tips in Munday's Hill Pit and one from Harris's Pit. He suggests that they indicate the presence of an ammonitiferous horizon below that of the basal nodule bed of the Upper Gault. The only fossiliferous nodules we have found *in situ* in the upper part of the Lower Gault have yielded us little besides

Inoceramus and the long-ranging *Anahoplites planus* (Mantell). A single small *Dipoloceras cristatum* (Brongn.) picked up loose in Harris's Pit is probably derived from the main nodule bed at the base of the *orbignyi* Sub-zone.

Harris's Pit, where the nodule bed is very fossiliferous, now shows little of interest. The pit was left so long unworked at the beginning of the late war that the lower part was hopelessly filled in with slipped clay and is now abandoned.

Chamberlain Barn Pit.—This pit is now about twice the size it was at the time of Lamplugh's description in 1922. At its northern end there is from time to time a magnificent exposure of the clays of the upper *regularis* and *mammillatum* Zones. The average thickness is 10 feet for a distance of over three hundred yards. The rock is a brown or grey sandy or gritty clay with bands of gritty phosphatic nodules, disposed as in Text-fig. 1.

The conglomerate bed (2) consists chiefly of more or less worn fragments of iron pan, as on Shenley Hill itself, but includes also pebbles of Shenley Limestone from the lenticles.

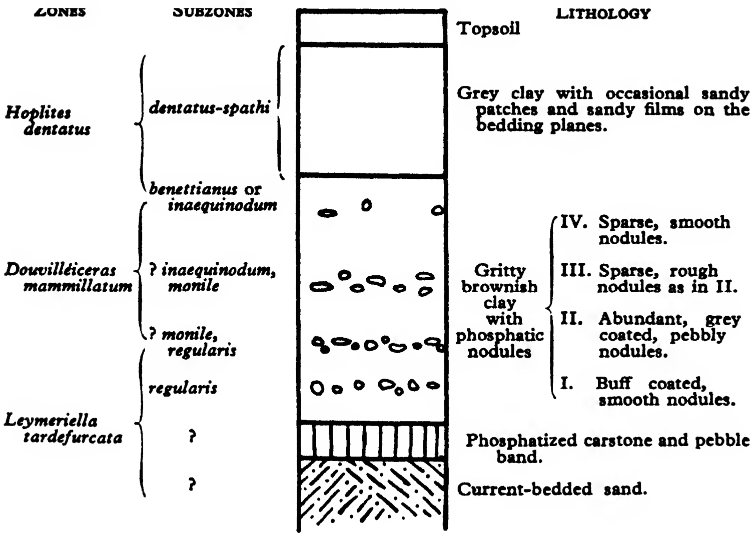
The majority of the buff- or grey-coated nodules in bed 3 are cylindrical or very irregular in shape, varying from a few inches to over a foot in length. Most are unfossiliferous. Although there is no strict separation into bands, the nodules are mainly concentrated at three levels (I to III in Text-fig. 1). Those in band I are commonly sandier and more ragged than the remainder. In band II large flattish nodules occasionally occur and these are sometimes crowded with fossils in the form of casts. Scattered fossils, mainly ammonites and gastropods, preserved as buff phosphatic casts, occur both in and between the nodule bands.

Beudanticeras ligatum (Newton and Jukes-Browne) is very common in and around band II ; *B.* "*dupinianum* (d'Orb.) ", *Douvilleiceras mammillatum* (Schloth.), *D. monile* (J. Sow.), *D. inaequinodum* (Quenst.) and *Cleoniceras* spp. also occur. A few specimens of *Hoplites* have been found (including *H. bullatus* Spath) in band III, where fossils are rarer than in II. We have only found a few small specimens of *Leymeriella* in this pit, although Lamplugh (1922) recorded them as abundant. All the fossils, however, are patchy in occurrence.

Arnold's Pit, Billington Crossing.—A good exposure has been visible for some years in Arnold's (formerly Pratt's) Pit, just north of the level crossing. There is a sloping face of clay, above the sand, kept clear by an endless bucket-chain excavator. In the 5 feet of sandy brownish clay thus exposed below the grey clays of the *dentatus* Zone of the Lower Gault fossiliferous nodules occur in three or four rather ill-defined bands. The bottom three probably correspond with those seen at Chamberlain Barn.

The clay is separated from the sands below by a thin bed of indurated pebbly sand, containing fragments of carstone, the whole sometimes phosphatized. The only fossils we have found in this bed are pieces of wood and specimens of *Entolium orbiculare* (J. Sow.).

The first layer of nodules occurs from 9 inches to a foot above the base of the clay and comprises fairly smooth dark brown phosphatic nodules with pale brown crusts. They commonly contain small



TEXT-FIG. 2.—Diagrammatic section of upper part of Arnold's Pit, Billington Crossing.

specimens of *Leymeriella regularis* (Brug.) and several species of gastropods and lamellibranchs. Crushed specimens of the ammonite have recently (Wright, 1946) been recorded from the sandy clay in which the nodules are embedded.

The next layer, 2 to 2½ feet above the base of the clay, consists of abundant irregular, round, elongated or flattened nodules, blackish inside with a grey outer surface studded with pebbles. Small *Leymeriella tardefurcata tardefurcata* (Leym.) and *L. t. intermedia* Spath are the commonest ammonites but *L. regularis* (Brug.) also occurs. Fragments of large specimens of *Beudanticeras ligatum* (Newton and Jukes-Browne), which were over a foot in diameter when complete, are frequent. Small molluscs and other fossils are abundant. Pieces of wood, sometimes as much as a foot long, occur ; they are usually coated with a layer of phosphatic material.

The third band, 3 feet 4 inches to 3 feet 10 inches above the base of

the clay, consists of sparse, irregular nodules, usually small. It may be divisible into an upper and a lower part, but the present exposure does not conclusively demonstrate this. This band has yielded a number of rather large specimens of *Cleoniceras*, *Sonneratia*, and *Douvilleiceras*; rare specimens of *Hoplites* also occur; they include *H. pseudodeluci* Spath, *H.* cf. *baylei* Spath, and *H.* cf. *devisensis* Spath, all of which are found in the *inaequinodum* or *benettianus* sub-zones in the south-west of England. Scattered fossiliferous nodules, less pebbly and smoother than those below, form an indistinct band at about 4 feet 6 inches above the base of the clay. They yield occasional ammonites.

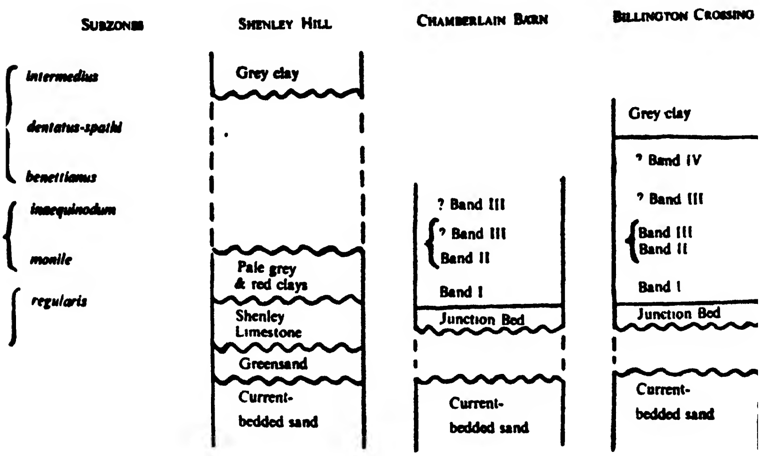
The distribution of the species of ammonites in these nodule bands (I to IV, from below upwards) is given in the table below, which is based partly on our own collecting and partly on an examination of material in the British Museum, Natural History, collected in recent years and, fortunately, labelled for the most part with the height in feet and inches above the base of the clay. There is available so little exact information about the detailed distribution and succession of most of the ammonites of the upper part of the Lower Albian that we feel that it is of great importance to put on record the fullest particulars, so that they may be compared with the faunas of the other more or less incomplete successions.

	Nodule Band.			
	I.	*II.*	*III.*	*IV.*
Eogaudryceras shimizui Breistr.[1]		II		
Aconeceras sp.	? I	II		
Beudanticeras ligatum (Newton and Jukes-Browne)	I	II	III	IV
Douvilleiceras inaequinodum (Quenstedt)			III	IV
„ *mammillatum* (Schlotheim)		II	III	
„ *monile* (J. Sowerby)			III	
Leymeriella regularis (Brug.)	I	II		
„ *tardefurcata tardefurcata* (Leymerie)		II		
„ *tardefurcata intermedia* Spath		II		
Cleoniceras aff. *baylei* Jacob		II		
„ *leightonensis* Spath				IV
„ *morgani* Spath				IV
„ *subbaylei* Spath			III	
Sonneratia kitchini Spath		II	III	
„ aff. *kitchini* (transitional to *obesa* Spath)		II		
„ *obesa* Spath			III	
„ aff. *parenti* Jacob		II		
„ aff. *sarasini* Jacob		II		
Hoplites cf. *baylei* Spath			III	
„ cf. *devisensis* Spath			III	
„ *pseudodeluci* Spath			III	
Protanisoceras cf. *raulinianum* (d'Orb.)		II		

[1] = *Gaudryceras aeolum* Jacob 1908, plate i, figs. 14–16, NON *Hemitetragonites aeolus* (d'Orbigny). See M. Breistroffer, Revision des Ammonites de Salazac (Gard), *Trav. Lab. Géol. Grenoble* (1938–39), tom. xxii, 1940.

The grey clays of the *dentatus* Zone contain many fragmentary *Hoplites* (including *H. dentatus* J. Sow. sp., *H. spathi* Breistr., *H. paronai* Spath, *H. rudis* Spath, and *H. persulcatus* Spath). *Neohibolites* is extremely common, especially in occasional sandy layers at the base of the clays. Lamellibranchs are frequent, particularly *Inoceramus concentricus* Parkinson and *Nucula pectinata* J. Sowerby. Well-preserved carapaces have been found of the usual crabs, *Notopocorystes stokesi* (Mantell) and *Etyus martini* Mantell.

The phosphatic nodules from this zone are readily distinguishable



TEXT-FIG. 3.—Summary of the succession in the Leighton Buzzard district.

from those of the beds below by their smoothness and freedom from included pebbles.

The section at Billington Crossing is summarized in Text-fig. 2 and zonal attributions are there made on the strength of the ammonites listed in the table above. It should be noted that these attributions are only provisional since there is still much to be learned about the exact range of the various ammonites in this part of the Albian and the species so far collected at Leighton Buzzard probably form only a small part of the local fauna.

The Relation between the Shenley Limestone and the Nodule Beds of Billington Crossing.—As Lamplugh (1922) observed, the section at Chamberlain Barn provides the clue to the relationship between the two facies that have yielded *Leymeriella*. There the gritty brown clays with phosphatic nodules rest on a conglomeratic "junction" bed composed chiefly of pieces of iron pan, more or less waterworn, but also yielding occasional pebbles of Shenley Limestone. The only possible conclusion is that the Limestone belongs to a horizon earlier

than that of the Nodule Beds. The nodule bands at Chamberlain Barn appear to correspond with those at Billington Crossing, so far as they go, and, therefore, if the zonal attributions in Text-fig. 2 are correct, the Limestone may be referred to the *tardefurcata* Zone, and probably, to the lower part of the *regularis* Sub-zone thereof. Text-fig. 3 gives a summary of the succession in the Leighton Buzzard area. As stated above the Shenley Hill section is fragmentary and the pale grey and red clays, and Lamplugh's Greensand bed below the Limestone cannot be placed with certainty.

The close connection between the Limestone lenticles and the facies with phosphatic nodules is shown by the occurrence in the latter of several of the peculiar Shenley Limestone fossils such as *Rhynchonella mirabilis* Lamplugh and Walker, *R. leightonensis* L. and W., and *Conulopyrina anomala* Hawkins.

Nomenclature.—The beds described above have been referred at different times to the Gault and the Lower Greensand. The fact that they are clearly of Lower Albian date does not mean that they should not be designated by the latter term. They correspond in part with the " *mammillatum* Bed " of south-eastern England and in part with the underlying Folkestone Sands. We are strongly of the opinion that the name Folkestone Beds should be applied to all marine sands, sandy-clays, or other rocks that can be shown to be of Albian date and lie between the top of the Aptian and the base of the true Gault clay, usually in the *dentatus* Zone.

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The History of the German Geological Survey

By Alfred Bentz, Geologisches Landesamt

A paper read to a party of British Geologists visiting Celle, July, 1946

THE "Prussian Geological Survey" was formed in Berlin on 1st January, 1873. This was the final step in a development which started at the very beginning of the science of geology. It soon became apparent that the best way to present the geological observations made in the field was to have them printed on maps, which could easily be re-studied and corrected by subsequent surveyors. Besides this the collection of geological observations forms the base for the application of geology in mining and for other economic purposes. Geological maps soon proved to be indispensable.

In Prussia, the Ministry for Commerce, Trade, and Public Services was highly interested in these surveys. The mining authorities were ordered to start with a geological survey of the country. Previously in 1841 they had formed a commission for surveying, of which many teachers of the high schools were members besides miners with geological interests. From 1835 onwards the general map of the Rhineland and Westphalia, published by von Dechen on a scale of 1 : 80,000, was considered a standard work of its time. For detailed field work larger scales were used. A more widespread use of these maps was hampered by the fact that they were not printed. The situation changed in 1866. From then on, the 1 : 25,000 scale was used for detailed mapping which subsequently proved so highly efficient.

The desire for geological maps was widespread in all parts of the country. In 1867 a conference of North German Geologists drafted an extensive programme for geological mapping aiming to transmit profitably the scientific results of geological surveying to practical life. The same conference also passed a resolution to have Prussia and Thuringia jointly mapped. The necessity was stressed for a standard stratigraphy and a uniform legend. This gigantic task of mapping had to be planned as a long-term programme, and the best way to carry out this programme was thought to be to entrust it to a special scientific organization, the Prussian Geological Survey.

Already before the Geological Survey was formed it was evident that the main task of the new organization was to act as an intermediate between science and economics. As regards the scheme of the organization two famous models were already in existence : first, the Geological Survey in London, formed already in 1835 and closely connected with mining and with the education of mining students. At that time it consisted of four departments :—

(1) The Geological Mapping.
(2) The Royal School of Mines.

(3) A Museum of Economic Geology.

(4) The Mining Record Office, an authority which kept the records and statistics of the mining products.

Geological maps were published on the scale of 1 : 63,360, in the more important mining districts even on 1 : 10,560. The Survey, with its four branch offices, kept at that time forty-seven scientific employees on the pay-roll.

In contrast with the Geological Survey in London, with its close association with mining and teaching, the Austrian Geological Survey in Vienna, formed in 1849, was quite independent of the mining authorities and the High Schools. It was self-contained as regards its scientific organization.

The development of geological surveying in Prussia and its close contact with practical objects definitely tended to follow the British example. The Geological Survey in Berlin was joined with the Mining Academy, founded in 1860, under the same direction and in the same building. Furthermore, a Museum of Economic Geology was added. The first budget of the new organization amounted to 46,000 thaler for 1873, compared with 32,000 thaler of the Vienna budget and with 73,000 thaler of the London budget. The number of scientific employees amounted to twenty-three. At first the connection with the Mining Academy proved a success. But it soon turned out that the requirements of teaching could not be reconciled with the necessities of geological field work. The technical development of mining led to specialization of the studies for mining and the introduction of numerous branches which no longer had any connection with geology, and in 1916 the Mining Academy was separated from the Geological Survey. The Academy was merged in the mining section of the Technical High School at Charlottenburg ; the Museum of Economic Geology, the library, and all the collections remained with the Geological Survey.

Both the science of geology and the Geological Survey originated from mining. But later development severed the connections and finally geology became an independent branch which wanted freedom for its further growth. The relation between mining and geology has become inverted : geology is now conceivable without mining, but mining is no longer conceivable without geology.

The ties between the Geological Survey and the High Schools were more elastic. Numerous geologists of the Survey acted simultaneously as Professors at the Mining Academy or at other High Schools, even outside Berlin. On the other hand Professors altogether outside the country were active in mapping as " foreign " collaborators. There was always a constant flow and exchange of opinions and it was the system of voluntary collaborators that proved so effective. The vast

experience, gained by the mapping geologists in the course of time, led to their being elected to professorial chairs at High Schools, thus further strengthening the ties between Geological Survey and High Schools.

The principal difference between the High School's activity and that of the Geological Survey consists in the fact that the latter is bound to carry out certain tasks which have to be assigned to the geologists, whereas the High School professor is absolutely free in the choice of his research work. As there is a great choice of research work to be done by the Geological Survey, the freedom of the individual explorer is also fortunately preserved to a high degree. On the other hand, certain modern research methods cannot be carried out by most of the small High School Institutes, both on account of lack of funds and of rapidly changing scientific personnel. A typical example is offered by the development of geophysics, of which only the basic knowledge can be taught at the High Schools. The application for practical purposes, the examination and development of new methods, require such close connection with geology as only the well equipped Geological Survey can afford. The same holds good for micro-palaeontology, petrology of coals, and other modern research methods, the results of which are based on a large amount of basic material which can only be secured by an adequate organization. In contrast with the High School the Geological Survey is faced with the important task of linking together the modern methods of research and carrying out of joint programmes. The results of the systematic investigation of the sub-surface geology of North-West Germany give evidence that important economic successes were achieved. New reserves of oil and iron ores were discovered by the combined efforts of geophysics, micro-palaeontology, heavy minerals, and palaeogeography.

After the resolution of 1866 to publish the geological detail-mapping on the 1 : 25,000 scale, the first maps of this series were produced in 1870, even before the Geological Survey was formed. The first edition comprised six sheets of the Harz Mountains, the second edition in 1872 six sheets of the surroundings of Jena, while the third edition, also in 1872, was again devoted to six sheets of the Harz Mountains. Besides the Harz Mountains, with their important ore-mining, other areas of mining interest were mapped. From 1868 on, Saarbrücken was surveyed, 1871 the Mansfeld district, 1873 the province of Hessen-Nassau. Right from the start the mapping of the low country was planned in order to investigate the pre-Diluvial beds and to obtain some clues regarding the occurrence of economic deposits. Although the difficulties were underestimated at the time, the general conception shows the intention to use the maps as a reliable guide for all purposes of practical life, for mining, quarrying, agriculture and forestry, public

services, etc. This aim should also be achieved in the low country by carrying out deep boring trials on behalf of the Geological Survey, a plan which was frustrated by the high drilling costs. Not until 1905 was a small drilling outfit acquired, capable of drilling down to 100 m depth, which solved a few scientific problems, especially of a stratigraphical character.

In all, more than 1,400 sheets of the geological detail map 1 : 25,000 were published, of which more than 500 sheets are out of print and others hopelessly out of date. The figures for the British Zone are :—

	AREA OF BRITISH ZONE, GERMANY	105,900 sq. km.
I.	Total number of topographical sheets 1 : 25,000	956
	Geologically mapped and published	447
	Not yet geologically mapped	509
II.	Total number of topographical sheets 1 : 200,000	36
	Geologically mapped and published	7
	In printing	2
	Not yet geologically mapped	27

On account of the fact that the general maps were lagging behind, large areas of the country are still without a modern geological map. In future provision should be made to fill these disturbing gaps. Though the 1 : 25,000 scale proved satisfactory in the hilly country, this does not apply to the surveying in the low country where the results did not meet with the expectations. A quicker and more efficient solution of the problems involved will be achieved by general maps, scale 1 : 100,000 or 1 : 200,000, than by continuing on the 1 : 25,000 scale. On the other hand the 1 : 25,000 scale is not satisfactory for agricultural problems. For these purposes and engineering problems still larger scales, 1 : 10,000 or 1 : 5,000, may be required. In future, mapping should not invariably stick to the 1 : 25,000 scale, but should carefully examine which scale is best suited for the purpose in question. Modern printing devices may considerably reduce the costs of publication and the respective number of copies should be fixed after a thorough examination of the market position.

Together with the mapping technique the Geological Survey developed exact methods of observation which form the base for the practical interpretation of maps and even of geology as a whole. There is ample evidence to prove that geology is useful in many sections of our daily life. It is of prime importance that geological advice should be taken in drafting long term plans. Engineering geology of to-day is still mainly based on experience, but efforts are being made to determine more accurate methods. Technical reports should be based on geological methods and be guided by the geological way of thinking. The Geological Survey acquired a leading position in advising various authorities and industries from the experience of its individual members and the team work of its staff.

At the time when the Geological Survey was formed, interest was concentrated on purely scientific problems, such as stratigraphical correlation or palaeontology. During later development interest was shifted more and more to economic geology. From the beginning this development affected the appointment of staff. Not only were good geologists required, but those with a definite inclination towards practical problems. It soon turned out that narrow-minded specialists met the requirements less satisfactorily than those geologists who had been brought up on a broad grounding. Especially from 1900 on, economic geology was fostered at the Geological Survey, and the youngsters had to make themselves familiar with all its branches. Every second day between 1908 and 1913 an expert report on water supply, medicinal springs, dams, engineering problems, rail, road, and tunnel constructions or on mining left the office. This work increased considerably, and in 1936 one expert report a day was written.

The mining activities of the Geological Survey were not only confined to mapping and the investigation of mineral deposits in Prussia, but closely followed the development with international collaboration. The publication of the two former presidents of the Geological Survey, Beyschlag and Krusch, on economic deposits, was a standard work in its field. Thanks to the intense activity of a number of geologists, mining, which previously had been a matter of the miners only, was developed into the geological science of mineral deposits. The exploration of new mining districts is now inconceivable without this branch of science.

Apart from the purely geological exploration of individual deposits, records of reservoirs and production were kept. The Geological Survey always contributed to the mining statistics of the German Reich and edited a monthly paper, the *Lagerstättenchronik*. At longer intervals a *Weltmontanstatistik* was published, and news of mineral deposits collected in the *Montan-Archiv*. The Geological Survey also contributed to the great estimates on reserves of iron ore and coal initiated by the International Geological Congress. These widespread activities were reflected in a large series of publications. The detailed map from 1870 on has already been mentioned. In 1872 the *Abhandlungen* followed, of which ten volumes were published. From 1889 on, the *Neue Folge*, comprising 209 Hefte up to 1944, was edited. The *Jahrbuch der Preussischen Geologischen Landesanstalt* began in 1880, and has excelled in its numerous plates and maps. The last volume was published in 1942.

Beginning in 1910, seventy-seven volumes of the *Archiv für Lagerstättenforschung* have been published. After the first world war these series of publications were continued, but unfortunately a number of special series were introduced which sometimes render

reference more difficult. From 1920 on the *Mitteilungen aus den Laboratorien der Preussischen Geologischen Landesanstalt*, Heft 1–21, were published ; since 1926 the *Mitteilungen der Abteilung für Gesteins-, Erz-, Kali- und Salzuntersuchungen*, Heft 1–7 ; since 1929 the *Arbeiten aus dem Institut für Palaeobotanik und Petrographie der brennbaren Gesteine*, 5 volumes ; since 1929 the *Beiträge zur physikalischen Erforschung der Erdrinde*, 8 Hefte, and finally since 1940, *Die wichtigsten Lagerstätten der Erde* (the most important mineral deposits of the world), 16 Hefte.

For uniformity's sake it would have been preferable to have these papers published in the *Jahrbuch* or the *Abhandlungen.*

The editions of geological maps also show great variety. Apart from the standard detail map (1 : 25,000), a number of general maps were published on the scales of 1 : 100,000 and 1 : 500,000. Germany should be mapped in total on the 1 : 200,000 scale. Thirty sheets have been published up to now. Highly important is the map of economic deposits, seventy sheets of which have been published since 1904. The too close connection was not a success between statistical information, which rapidly gets out of date, and geological observations, which remain relatively unaltered. We must endeavour to find a better form of presentation in the future. A special map (1 : 25,000) of the coal seams was published together with the 1 : 25,000 geological map in the German coal districts. Beside this, in the Ruhr area a map of drilling locations, scale 1 : 100,000, was printed. The general map of Germany, scale 1 : 2,000,000, was printed in a 30,000-copy edition to meet a most widespread public.

The organization of the Geological Survey did not keep pace with the growing extension of its tasks during the last decades. At the beginning the organization was mainly concentrated on the main task, surface mapping. There were five departments :—

I. Mapping of the hilly country.
II. Mapping of the low country.
III. Geological collections.
IV. Publications.
V. Chemical laboratories.

This scheme clearly shows that mapping was the essential point. It was not until 1926 that this rigid scheme was altered, when in place of a director for the collections, a director for geophysics was appointed. In 1932 this post was abolished and the pre-1926 conditions were re-established.

Conforming to the growing importance of economic geology, a number of heads of sub-departments and sections apart from the

directors were entrusted with the routine work of specially important tasks. In 1934 there were six heads of sub-departments on the following duties :—

(1) Middle German brown coal sub-districts.
(2) Ores.
(3) Soil science.
(4) Engineering geology.
(5) Analyses of rocks and minerals.
(6) East Prussia.

Apart from these duties there were the following sections :—

(1) Economic geology.
(2) Institute for rock, ore, and salt research.
(3) Institute for palaeobotany and petrology of coals.
(4) Institute for physical research work on the earth's crust.
(5) Mining and drilling archives.
(6) Institute for crude oil geology.

This scheme was neither clear nor did it guarantee a smooth conduct of the work. When in 1939 the Geological Survey was transformed into the " Reichsamt für Bodenforschung "—extending its duties to the whole Reich area—a fundamental reorganization took place which, however, did not satisfy everybody. Five departments were formed :—

I. Administration (staff and finance).
II. Geology.
III. Mineral deposits.
IV. Crude oil.
V. Geophysics.

Under the department Geology were placed the following sections :—

(1) Mapping of the hilly country.
(2) Mapping of the low country.
(3) Soil science.
(4) Hydrogeology.
(5) Engineering geology.
(6) Publications and printing.

Apart from this, there were the following independent sections :—

(1) Mining and drilling.
(2) Soil chemistry.
(3) Micro-palaeontology.

(4) Collections, library and retail service.
(5) Archives.
(6) Pre-history.

The change from the Geological Survey to the "Reichsamt für Bodenforschung" in 1939 was effected by uniting the surveys of the other German states—Saxony, Thuringia, Mecklenburg, Württemberg, Baden, Hessen, Bavaria, and Austria—with that of Prussia. The state offices were transformed into branch offices of the central "Reichsamt". Close co-operation had prevailed already in earlier days; Berlin had carried out the surface mapping in Thuringia and Mecklenburg from the beginning. But not only mapping called for co-operation between the various surveys; an exchange of opinion was urgently wanted regarding economic geology. From 1904 regular conferences of the directors of the German Geological surveys took place during which working programmes were discussed and joint operations were decided. Owing to increasing specialization the smaller German surveys, being understaffed, could not keep pace with the modern development. Saxony employed only 6 scientists, Thuringia 3, Mecklenburg 1, Württemberg 5, Baden 3, Hessen 3, Bavaria 8, and Austria 11.

It stands to reason that, for instance, geophysical methods could only be developed and applied by a greater unit. Specialists in micro-palaeontology, coal petrology, oil geology, heavy minerals could only be engaged by an office endowed with the necessary equipment and capable of offering the opportunity for a large-scale use. It was quite natural that the Berlin office was consulted at a growing rate on these special problems, and that it had to lend its scientific assistance to the smaller surveys. The 1939 scheme of centralizing the administration but leaving the surveys intact as branch offices is considered a good one. The administration was much cheaper and the new office even more efficient from a scientific point of view. The free exchange of staff members and their experience brought a spiritual refreshment to all offices.

Centralization is considered a necessity not only for the application and examination of modern methods of investigation, but also for the upkeep of well-equipped laboratories and of a large library. Centralization, however, may not be carried out schematically for field geologists who have to keep close contact with local authorities and services. In the British zone, therefore, more decentralization has been effected by opening new branch offices in the Northern Rhineland and in Westphalia.

Finally, I should like to present some figures, indicating the growth of the scientific staff of the Geological Survey. The figures include the so-called "foreign" collaborators of the High Schools.

	1873 = 23	scientists	
	1880 = 30	„	
	1890 = 36	„	
	1900 = 56	„	
	1914 = 61	„	
	1919 = 85	„	
	1926 = 104	„	
	1933 = 106	„	
	1938 = 122	„	
(Reichsamt)	1941 = 223	„	(including 40 scientists in the branch offices)

Reviewing the development of the Geological Survey it can be stated that its basic principles have been always the same : assembling a maximum number of the most accurate observations and recording and presenting them in geological maps. We also see that this entailed a growing penetration of geology by practical problems of mineral deposits, engineering geology, agriculture, and government plans—in short by all sections which are in any way connected with the subsurface. The history of the Geological Survey during the last seventy years is also a history of economic geology. This point must be made absolutely clear, in order to draw the right conclusions which shall guide the future. It must be emphasized that in future the main task of the Geological Survey will be the development of economic geology, because it will be economic geology that will play a dominant part in the reconstruction of Germany's economic life.

The Broadlaw "Granite"

By D. D. C. Pochin Mould

THE Broadlaw "Granite" is one of the small granitic intrusions of Caledonian age found in the eastern part of the Southern Uplands of Scotland. It is situated on the north-west flank of Broadlaw in the Moorfoot Hills, three miles south-west of Middleton House.

The grey granodiorite, which is the principal rock exposed in the main quarry, has been described by Walker (1925, pp. 357–365; 1928, pp. 153–162): two of the rock types were the subject of Lovegrove attrition tests (1929, pp. 20–1, 62–3). The Broadlaw quarry is said to have furnished the first setts for Prince's Street, Edinburgh (MacGregor, 1945, p. 25).

The granitic intrusion is elongated parallel to the strike of the Ordovician sediments into which it is intruded; its maximum length is under half a mile. The outcrop is, however, concealed under turf and peat except for a large quarry situated one-third of a mile from the Middleton-Innerleithen road, and a few minor trial pits. The contact of the intrusion with the surrounding greywackes and mudstones is nowhere exposed: hornfelsed mudstones and greywackes, in which plates of reddish biotite are developed, are seen in a small outcrop in the road cutting between Wull Muir and Broadlaw, close to the margin of the "granite".

The outermost and probably the earliest member of the Broadlaw mass is a hornblende-biotite-quartz-diorite, which is exposed in several small trial pits to the north-east of the main quarry. It is a very fresh, rather fine-grained rock, pale grey or buff in colour. Phenocrysts of plagioclase, biotite, hornblende, and quartz lie in a fine-grained granulitic matrix of quartz and orthoclase. There is accessory pyrite, magnetite, apatite, and zircon. The plagioclase forms euhedral crystals with well-marked oscillatory zoning: the cores of the crystals range from andesine to calcic andesine (An_{40-45}), the rims are oligoclase-andesine (An_{30}). The abundant biotite is strongly pleochroic from pale straw yellow to a bright foxy red; zircons enclosed in it are surrounded by well marked pleochroic halos. Green hornblende is much less abundant, and is usually found associated with knots of biotite. These knots of ferromagnesian minerals are sometimes several millimetres in diameter.

The junction between the hornblende-biotite-quartz-diorite and the granodiorites of the main quarry is not exposed. In the main quarry the principal rock-type is a grey granodiorite; in the south-east corner of the quarry it is seen to be cut by a red variety. Both types are well jointed and these joint faces are sometimes curved. The rocks are also traversed by a few minor lines of movement and crushing.

The granodiorites weather rapidly, but fresh material is readily obtained from blocks lying on the quarry floor and from the extensive spoil heaps.

The grey granodiorite is a medium-grained porphyritic rock composed of quartz, orthoclase, plagioclase, and biotite with accessory pyrite, apatite, and zircon. Quartz and orthoclase form a fine-grained, granulitic matrix in which lie the euhedral phenocrysts of plagioclase and biotite, with occasional phenocrysts of quartz. Again the plagioclase shows marked oscillatory zoning : the cores are sometimes as basic as labradorite (An_{60}), the rims are calcic oligoclase (An_{25}). The biotite is usually entirely altered to penninite ; when fresh it is pleochroic from light to dark and rather reddish brown. Enclosed zircons are surrounded by pleochroic halos. Pyrite is a common accessory. Calcite is sometimes introduced secondarily. The rock shows some variation in the relative proportions of phenocrysts to matrix.

The red granodiorite differs from the grey variety in its red colour, more even texture, and slightly more acid composition. It is usually more altered than the grey type. The plagioclase is always sericitized. It is a sodic oligoclase (An_{20}) and is often unzoned.

Small xenoliths, ranging in size from an inch to a foot in length, are found in all three rock types. Some of these xenoliths are altered shales and mudstones. At the entrance to the large quarry a hard, compact, and completely unweathered black hornfels is found as nodules and lenticles in very highly decomposed granodiorite of the grey type. The hornfels consists of a fine-grained mosaic of andesine and quartz, with decussate flakes of red "hornfels" biotite and ragged crystals of pale green actinolite. A little pyrite and magnetite is present together with a few tiny grains of corundum. A coarser-grained type of xenolith of sedimentary origin is rich in "hornfels" red biotite, the flakes of which, however, still retain a common foliation. The matrix of this rock consists of andesine and a little quartz. Corundum, sometimes in quite large crystals, is fairly common ; in thin section it is sometimes blue and pleochroic. In one such xenolith, a little sillimanite is associated with it. Pyrrhotite is present in addition to pyrite. Other medium-grained, unfoliated xenoliths, rich in reddish biotite resemble kersantite in composition and character. Another coarse-grained, basic inclusion was composed of felts of red biotite and stout prisms of green hornblende : the latter enclosed in large, clear, interlocking plates of andesine. These two types were found in the grey granodiorite only.

It is noteworthy that in the immediate vicinity of these xenoliths, the biotite of the grey granodiorite, normally chloritized, is quite fresh.

Streaks of pink micropegmatite, composed of a micrographic

intergrowth of quartz and orthoclase, are sometimes found in the grey granodiorite. They usually surround small lenticles of a soft, green, colloidal mineral with a marked conchoidal fracture. This mineral appears to be cornuite (mCuO.nSiO$_2$.H$_2$O). It may be pertinent to recall in this connection that copper ores are associated with the Priestlaw " Granite " in the neighbouring Lammermuir Hills (Pringle, 1935, p. 96). The Broadlaw " granites " are also veined with quartz and with some of the veinlets both arsenopyrite and pyrite are associated.

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A Tooth of *Elephas primigenius* from Headswood, Larbert, Stirlingshire

By R. GREGORY ABSALOM and STUART M. K. HENDERSON

1. INTRODUCTION

TOWARDS the end of January, 1937, an interesting discovery was made at the sandpit belonging to the Headswood Sand and Gravel Company. The sandpit lies a little north of the point where the road from Larbert (Stirlingshire) forks for Dennyloanhead in the one direction, and Denny and Dunipace in the other. It is located immediately west of Headswood Farm, Stirlingshire (O.S. Sh. 24 S.W. 6 in. to 1 mile).

An object believed to be a fossilized fish was dug out of the sand and eventually thrown on one side as of no importance. Later it was taken home by one of the company's lorry drivers. Shortly afterwards Mr. J. Shields, of Stirling, a local antiquarian, visited the sandpit and was informed of the find. He sought the driver and obtained his consent for the specimen to be brought to the authors at the Glasgow Art Gallery and Museum. It was immediately realized that this specimen was part of a badly weathered mammoth tooth and through the good services of Mr. Shields it was presented to the Museum (Registered Number : '37–26).

2. THE GLACIAL DEPOSITS AT HEADSWOOD

Under the guidance of Mr. Shields the authors visited the site of the discovery. The sandpit proved to be located at the south-east of a glacial deposit marked on the O.S. Stirlingshire Sh. 24 S.W. as " The Kames ". This sinuous glacial deposit stretches from Leslie Park in a south-east direction, parallel to the valley of the River Carron, to Headswood, and then turns east-north-east across the present course of the river. The base of the deposit runs along the 100-foot contour while its highest point is 138 feet O.D.

The removal of some 50,000 tons of material by the Headswood Sand and Gravel Company has exposed an excellent section of the deposit. The upper 38 feet is composed of almost unstratified sand and gravel. What slight traces of stratification there are indicate a general dip in an easterly direction. This gravel contains rounded material ranging from pebbles 1 inch in diameter to boulders over 1 ft. 6 in. in diameter. The majority of the material is porphyry, but there is also a considerable number of pebbles of local Carboniferous sandstone, Carboniferous lavas of the Kilsyth Hills to the west, and Old Red Sandstone rock. Pebbles of schist and schistose grit are the main representatives of the Highlands. The gravels are intermingled with sand.

Below the gravel more than 25 feet of clean, false bedded sand has been exposed, but at the time of investigation by the authors the base of the sand had not been reached. The current bedding is accentuated by the presence of black streaks of fine coaly matter. The direction of the false-bedding in two areas of the excavation appears to indicate that in all probability the water depositing the sand flowed from north-west to south-east.

3. The Tooth and its Preservation

The mammoth tooth with which this paper is concerned was discovered approximately at the line of junction between the upper coarse sand and gravel and the lower fine yellow sand.

Only the central portion of the original tooth remains, the grinding ridges and the root fangs having been worn away. It measures 4½ inches in length and 3½ inches in depth, while the greatest breadth is 4 inches. In all eleven plates have been preserved, the anterior and posterior portions being absent. In all probability it is the remains of a right upper molar tooth of *Elephas primigenius*, but the bad state of preservation prevents accurate identification.

When the tooth was received from Mr. Shields it was sodden and crumbling away rapidly. It was decided that the only method of preventing further disintegration was to treat the tooth by the bakelising process. Dr. Henderson carried out the preservation.

The specimen was cleaned carefully and saturated with alcohol, which was allowed to evaporate at ordinary atmospheric temperature. The tooth was then placed in a specially built oven and slowly dried out to remove all trace of moisture. A solution of Bakelite Varnish, consisting of 75 per cent varnish and 25 per cent thinner, was prepared, and the tooth immersed in it for twenty-four hours when it was estimated impregnation would be complete. On removal the specimen was allowed to drip and dry slightly before being placed in the oven which was at a temperature of about 30° C. Precautions were taken to prevent any bakelite varnish collecting on the surface, any drops which collected being wiped away with a cloth saturated in thinner. When the specimen had dried sufficiently to prevent any collection of varnish on the surface the temperature in the oven was raised slowly until it reached 135° C. This temperature was maintained for about thirty minutes, when it was considered that polymerization would be complete. The temperature was lowered gradually and the specimen allowed to cool slowly. The treatment was entirely successful and the specimen can be handled without any risk of damage.

4. Previous Recordings

Professor J. W. Gregory and Dr. E. D. Currie (1928) have recorded in a Monograph of the Hunterian Museum previous finds of *Elephas*

primigenius in Scotland. It is stated that a right upper molar tooth from Bishopbriggs, Glasgow, has no ice scratches and like the tooth from Baillieston, recorded by Kirsop (1882), was recovered from the sands below the Boulder Clay. A portion of a molar from Kilmaurs, Ayrshire, is stated to have come from below material containing arctic marine shells and resting on Middle Boulder Clay.

Writing on the distribution in Scotland, the authors of the Hunterian Monograph stated that except for Kinloch, near Blairgowrie and Kimmerghame, in Berwickshire, both of which are uncertain records, the finds at Bishopbriggs in the west and at Clifton Hall, near Edinburgh, in the east, indicate the most northerly known line of range of the mammoth in Britain.

While this new find at Headswood moves the limit a little further north, the range of the mammoth might still be below the line of the possible sea across the Midland Valley suggested by Professor Gregory and Dr. Currie as preventing the passage of the mammoth further northwards.

The finding of this specimen at Headswood has been mentioned by A. D. Lacaille (1945 and 1946).

5. Glaciation of the Carron Valley

Although Headswood is the locality at which this mammoth tooth was found it seems doubtful if this was the actual final resting place of the animal. In all probability the molar was brought from a point further to the north-west by water from the retreating ice. There are, throughout the district, glacial sands and gravels resting on either boulder clay or solid rock, and these deposits, containing well water-worn pebbles, are, then, more recent than the boulder clay.

"Kames" in the form of knolls, hummocks, banks, ridges, and mounds occur at many different levels, the most notable being the Polmont Kame described fully by Professor J. W. Gregory (1911). The glacial deposits forming ridges across the Carron Valley cannot be ascribed to the same origin as the Polmont Kame. They are more in the nature of terminal moraines due to retreat phenomena of the ice occupying the Carron Valley. The furthest advance of the ice down the valley is indicated by a north to south ridge of gravel situated a little west and south of Larbert (Text-fig. 1—I). The river meanders along the western side of this barrier before breaking through a narrow gap at the northern extremity. The ice in its retreat up valley paused to form a second barrier (Text-fig. 1—II) east of Dunipace House. A section of this deposit is well seen in a sandpit just north-east of Ruchmute Farm. A third and minor pause in the retreat formed "The Kames" at Headswood, where the mammoth tooth was discovered (Text-fig. 1—III). This was closely followed by a fourth

pause giving rise to a crescentic deposit (Text-fig. 1—IV) which effectively blocked the Carron Valley and forced the water to utilize spillways on each flank of the barrier. The southern spillway flowed between the barrier and " The Kames " and at one period was probably occupied by the Little Denny Burn now diverted to a channel south of the Kames. The northern spillway passed round the end of the barrier just north of the present gorge-like gap through which the River Carron now flows.

Outwith the actual Carron Valley area are violently false-bedded sands extending from Denny Cemetery in the west to Larbert in the east. In some places overlying gravel ridges show an abrupt junction with these strongly false-bedded sands. It seems probable that the deposits are a remnant of an alluvial flat over which the ice flowed prior to retreating to form the gravel ridges described above. It is possible that the mammoth remains were originally deposited in a part, now non-existent, of a wide-spread alluvial flat.

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ANNOUNCEMENT

INTERNATIONAL GEOLOGICAL CONGRESS

XVIII SESSION, LONDON, 1948

The XVIII Session of the International Geological Congress, originally planned for 1940 and postponed on the outbreak of war, is to be held in Great Britain in 1948, on the invitation of the Geological Society of London.

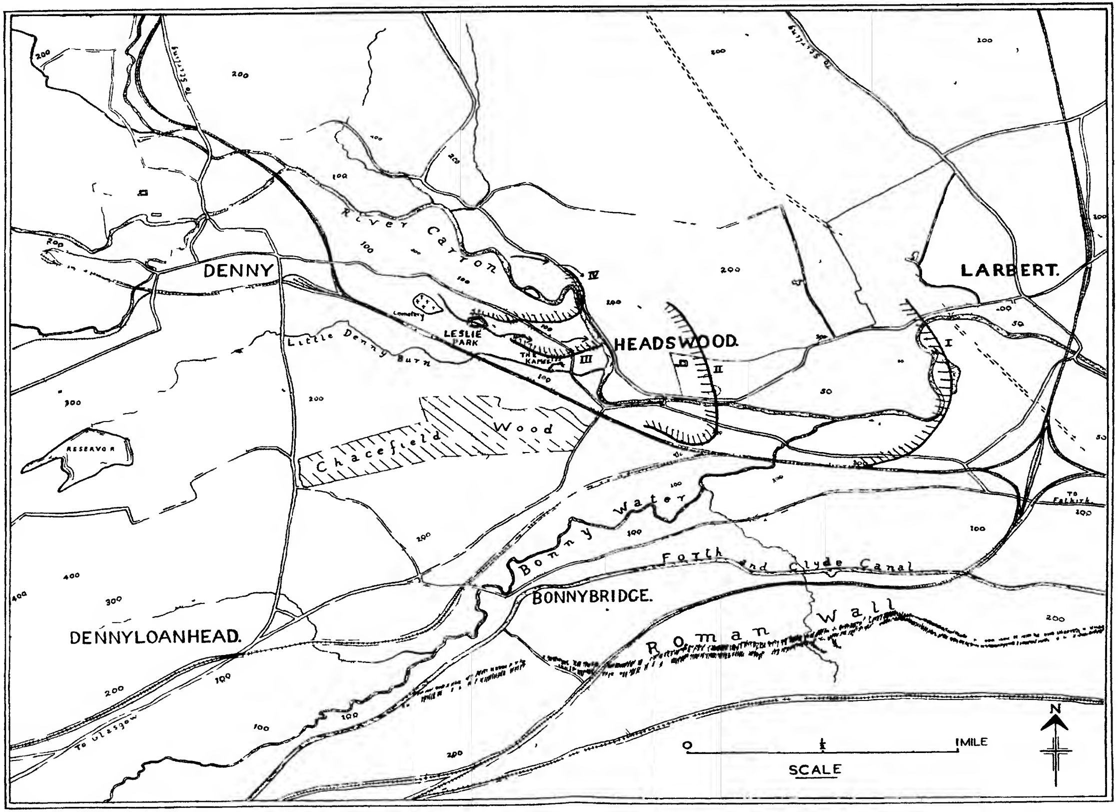
A Third Circular containing preliminary arrangements for the Session has been issued. Sessional Meetings will take place in London from 25th August to 1st September, 1948, and the following subjects have been provisionally listed for discussion :—

1. Problems of Geochemistry.
2. Metasomatic Processes in Metamorphism.
3. Rhythm in Sedimentation.
4. The Geological Results of Applied Geophysics.
5. The Geology of Iron-Ore Deposits.
6. The Geology of Petroleum.
7. The Geology, Paragenesis and Reserves of the Ores of Lead and Zinc.
8. The Geology of Sea and Ocean Floors.
9. The Pliocene-Pleistocene Boundary.
10. Faunal and Floral Facies and Zonal Correlation.
11. The Correlation of Continental Vertebrate-bearing Rocks.
12. Earth Movements and Organic Evolution.

The Circular gives details of geological excursions covering most of the British Isles, which are planned to take place between 7th August and 18th September, 1948, as part of the Congress programme. They include 16 long excursions (7–16 days) before the meetings in London, and 16 of similar length after the meetings. There will also be daily excursions, centred on London, between 22nd August and 3rd September.

The General Organizing Committee is anxious that the plans for the Session, which will be the first major international assembly of geologists for eleven years, shall be as widely known as possible. About 1,500 geologists, including some 800 from countries overseas, would have attended in 1940 if the arrangements for that year had not been disrupted by war ; it is hoped that the attendance in 1948 will be of the same order, and that it will include representatives of universities, geological surveys, geological and mining societies, and other interested institutions from most countries of the world.

Sir Thomas Holland, K.C.S.I., F.R.S., is President of the General



TEXT-FIG. 1.—Map of Carron Valley showing the position of the four gravel barriers.

[To face p 184

Organizing Committee and President-Designate of the Congress. The General Secretaries are Mr. A. J. Butler and Dr. L. Hawkes, and the Treasurer is Mr. F. N. Ashcroft. All communications should be addressed to the General Secretaries, XVIII Session International Geological Congress, Geological Survey and Museum, Exhibition Road, London, S.W. 7.[1]

24th April, 1947.

CORRESPONDENCE

Sir,—I am engaged on a nomenclatorial revision of Daniel Sharpe's *Monograph of the Chalk Cephalopods*, published by the Paleontographical Society. In this connection I am trying to trace the present location of all the specimens which he figured.

I have located those in the British, Geological Survey, and Norwich Museums, but there are still nearly fifty specimens unaccounted for, most important of which are those in the Wiest Collection which were not presented by that collector to Sharpe.

If any of your readers has any clue to the whereabouts of the Wiest collection or any knowledge of the presence of specimens figured by Sharpe in collections other than the three I have mentioned, I should be very glad to be informed.

Tower House,
North Ferriby,
East Yorkshire.

C. W. Wright.

4th May, 1947.

[1] Since the foregoing circular was set in type the death of Sir T. H. Holland has been announced.

REVIEWS

THE PULSE OF THE EARTH. By J. H. F. UMBGROVE. Second edition. pp. xxii + 358, with 204 text-figures and 11 maps and tables. The Hague : Martinus Nijhoff, 1947. Price 20 gilders.

The second edition contains approximately twice the number of pages, figures, and plates of the first, which appeared in 1942 and was outlined and reviewed in these pages (*Geol. Mag.*, lxxxiii, 46–7). This increase is due mainly to the insertion of three new chapters and the addition of an index. Chapter VI, The Continental Margin (47 pp.), conveniently summarizes many of the problems concerning submarine features with special reference to the evidence for changing sea levels and the formation of submarine valleys. Chapter VII, Island Arcs (72 pp.), is a valuable survey of the characteristics and theories of curved mountain chains and troughs. The author is well qualified to summarize the geological and geophysical data from the East Indies. XI, the penultimate chapter, Linear Patterns (27 pp.), brings together some ancient and modern speculations about the face of the earth. The other chapters remain the same except for some rearranging and a few additions. The reference lists are enlarged, and to Chapter IV, on Crust and Substratum, a section on magmatic clans has been added, illustrated by an additional world map of igneous provinces at the end of the book.

Some might join issue with Umbgrove for going beyond the evidence in assigning movements to Stille's detailed syn-orogenic epochs, for favouring the migmatists, for rejecting continental drift, and indeed for taking a positive line in many controversial matters on which the more judicial mind would not commit itself. This, however, is the essential nature of the book. It is not our purpose here to consider such issues in detail, but to welcome the omnivorous appetite which has brought together so many problems whose answer concerns the inner mechanism or Pulse of the Earth ; to commend also the pre-digestion which has much simplified our own assimilation. The time is surely ripe for such imaginative syntheses. This volume serves essentially as a restatement in contemporary language of fundamental problems of geology.

In such a general study the wider range of material in the second edition is an undoubted advantage, and those who were disappointed not to obtain a copy of the first edition will be well satisfied to have waited. This fresh issue of clear maps and diagrams brightens the somewhat worn currency of geological illustration, and serves also to remind us of our debt to this prolific Dutch School.

W. B. H.

MICROTECTONIQUE ET TECTONIQUE PROFONDE. By ANDRÉ DEMAY, *Mem. Serv. Carte Géol. France.* pp. xx + 247, with 19 plates and 29 figures. Paris, Imprimerie Nationale, 1942.

In a recent discussion of the granite problem it was noted that the French school have of late years largely abandoned the petrological side and gone over to Alpine tectonics. However, the important memoir now under review has returned to older methods, as it is mainly based on small-scale petrography and microscope work. The author, who is Inspector-General of Mines and a professor at the School of Mines in Paris, deals mainly with the ancient rocks of the Central Plateau of south-eastern France, the Cevennes, Rouergue, the Lyonnais, Forez, Cantal and Corrèze : at the end these are briefly compared with other areas, viz., Scandinavia, Finland, and South-West Africa.

As is really indicated in the title, the main object of the memoir is the comparison of structures on all scales, and the general conclusion is that they are all the same whether in a mountain chain, a quarry, a hand specimen, or a microscope slide, the chief differences dividing them into two categories depending on whether magma has or has not played a part. It is impossible in the space here available to discuss the enormous amount of detail here described, which should be read carefully and is splendidly illustrated by the plates. Only one point will be mentioned here, viz., the definitions of the different types of granite, which are divided into *granite intrusif* and *granite profond.* But the author categorically explains that by intrusive he does not mean the irruption into an open space of a great mass of liquid magma, but rather a replacement, or in fact very much what most people understand by granitization, while his deep granite is essentially migmatite. Now to the present writer this distinction is by no means clear, here and elsewhere. It really seems to depend on whether the resulting rock is completely homogeneous (granitization) or whether it is obviously patchy ; as Sederholm said, whether it looks like a mixture. According to Monsieur Demay the deep granites are really the magmatic zone, migmatites or *granites francs*, whatever this may mean. He thinks that his intrusive granites are usually post-tectonic, i.e., later than the main orogenesis, while in the magmatic zone they are often earlier.

As usual in French publications there is no index, but an elaborate table of contents : a useful feature is a kind of glossary, with definitions of most of the terms used. The drawback to the proper appreciation of this memoir is its enormous weight, exactly 3 lb., it being the largest possible quarto with a three-inch margin all round the text, and hence at least twice as much paper as was necessary. This, however, favours the reproduction of the admirable plates.

R. H. R.

THE COASTLINE OF ENGLAND AND WALES. By J. A. STEERS. pp. xix + 644 with 114 text-figures, 115 photographs, and 2 plates in colour. Cambridge University Press, 1946. 42*s*. net.

Britain is a small island, but its long coastline includes samples of practically every type known to the physiographer. This is the first comprehensive account of the physiography of the whole coastline of England and Wales, and, as such, deserves the gratitude and respect of all, whether geographer, geologist, botanist, historian, or the amateur on holiday. The variety of our coastal physiography is reflected in the variety of its scenery, much of it extremely beautiful, none of it devoid of interest, and nearly all of it frequented by holiday makers in great numbers in the summer months. As such its preservation from spoliation and unsightly development is a national concern and it was only natural that the Ministry of Town and Country Planning should turn to Mr. Steers, University Lecturer in Geography at Cambridge, and leading authority on coastal evolution, for a report upon the whole coastline and advice on its preservation and development. This gave him the incentive and opportunity to visit or re-visit practically the whole 2,750 miles of its length in 1943 and 1944. But notwithstanding two introductory notes by Professor Dudley Stamp and Sir Patrick Abercrombie, the planner will probably prefer to consult the official reports, drawn up by the same author with the amenity aspect in view, unless he is unusually well equipped with geomorphological knowledge and understanding. For the present work was almost completed before 1943, and is born, as it was conceived, austerely objective and scientific. Mr. Steers is a geographer, but his book is geomorphological rather than geographical; the theme is the "Physical Basis", while the "Human Overlay" is recognized only in an occasional parenthetical comment on use or abuse by man. Characteristically, too, he is more interested in lowland coasts with their shingle bars, sand dunes, and mud-flats than in spectacular cliff scenery, and quite rightly so because they present a greater variety of more interesting problems, problems towards the solution of which the evidences from history, archaeology, old maps, botany, geology, palaeontology, surveying, and coastal engineering all contribute. In fact some of the most valuable and interesting chapters are concerned with the rates of accretion and the changes in form of such places as Scolt Head and Blakeney Point where he and his students have made accurate topographical and ecological surveys and measurements over a number of years. Quite naturally personal interest and familiarity have resulted in expanded treatment of some areas, and the availability of published studies has made possible a very full discussion of others, but no section of the coastline is neglected and the treatment has as fair a balance as it is possible to achieve.

The book is in the form of a sandwich; three opening chapters deal with the structure and physiography of England and Wales and with the processes of coastal erosion and deposition, leading to an explanation of the forms of cliff and beaches; three concluding chapters summarize and systematize recent vertical movements of the shore line, coastal dunes, and salt marshes; in between is the solid meat of the regional description and analysis of the coastline from Solway Firth counterclockwise to Berwick-on-Tweed. But although the east coast is divided into three sections treated in order from south to north, each section, rather contrarily, is described from north to south; the reasons given scarcely justify the breaks in continuity and the long backward jumps that the arrangement compels.

The early chapters admirably fulfil their purpose of placing the unspecialized reader in a position to appreciate the regional descriptions that follow, but he will sometimes feel the need to turn to the concluding chapters for a definition of such terms as "pre-Tardenoisian", "sub-boreal", etc., which are not explained until Chapter XII. The summarizing chapters naturally involve some repetition, sometimes with too little variation of treatment, but this is inevitable and they are a most valuable summary of our present knowledge, in which the author is scrupulously fair to the views and theories of all authors.

The problems of salt marsh and sand dunes are botanical and ecological as much as geomorphological, and contributions in these fields receive full recognition; but the non-botanist may be troubled by the Latin names of numerous marsh and dune plants, familiarity with which is taken for granted. A number of close-up and recognizable photographs or drawings of the more important of these would have helped to reveal the identity of at least the more familiar elements of the seaside flora.

115 beautiful and well chosen annotated photographs are bound in at the end of the book and constitute a very attractive pictorial atlas; they are arranged consecutively in the same way as the text and the position of each is shown on a key map. The 114 text-figures include many large scale maps, some of them folding. In clarity of lettering and line they are models of what a map should be, but the stipples and shading in many of them are insufficiently differentiated. The symbols used for sand, mud, shingle, and dune look so much alike that it is often impossible to tell one from another. The titles of 78*a* and *b* have got transposed.

In the hands of amateurs and professionals both at home and in the field this admirable scientific guide may be confidently expected to stimulate a wave of interest in and appreciation of our unrivalled coastline.

A. A. M.

AN OUTLINE OF LATE CRETACEOUS AND TERTIARY DIASTROPHISM IN NEW ZEALAND. By E. O. MACPHERSON. N.Z. (Dept. of Sci. and Indust. Res.) Geological Memoirs, No. 6. pp. 32 and 2 maps. 1946.

On Macpherson's maps, which show structural trends, Tertiary volcanic activity, and seismicity, a large amount of useful data is assembled, but the attempted correlation of volcanic phenomena and present-day seismicity with the diastrophism of earlier times is somewhat obscure and not altogether convincing.

The value of the author's contribution lies, however, not so much in the tectonic theory and discussion of structural lines as in his explanation of the process of development of persistent "structural highs" which he describes and on which he bases his main conclusions. The late Cretaceous and Tertiary marine formations of New Zealand he finds accumulated in two geosynclines, an eastern and a western, separated by a strip that was continuously emergent as a "median land" of variable width. In the opinion of the reviewer the latter point at any rate seems not to be established; but even if the structure and its history have been over-simplified this conception helps with the discussion of the problems that are encountered. Within each geosyncline the author finds evidence of intermittent growth of anticlines throughout the era of sedimentation. Though progressively reduced by erosion and for the most part resubmerged in successive periods "when the whole geanticline slowly subsided", so that over their crests and more particularly on their flanks relatively thin sedimentation took place, with numerous unconformities developing, the anticlines separate, or are alternate with, synclinal areas that persistently sank so that sedimentation continued in them uninterruptedly until 25,000 feet of strata had accumulated.

Much of this sediment accumulated very slowly. Until after the Oligocene "the prolonged sinking . . . was not associated with complementary rapidly rising highlands" such as would be a source of coarse sediments. The sediments were very fine in grain and light in colour. In the later Tertiary, however, sediments were formed that were darker and distinctly coarser; anticlines were emerging in the vicinity and erosion was exposing basement rocks. The orogenic rhythm was also accelerated, and discordances are numerous.

Though most of the evidence adduced suggests that movements were weak and of small magnitude in the early part of the era of sedimentation, this conclusion is subject to modification if the late Cretaceous age assigned to the Taitai overthrust, in the East Cape district of the North Island, is substantiated; but in the opinion of the reviewer this date is not established, though the Taitai overthrust sheet has not yet been found overlying formations younger than

(?) Santonian. As described by the author, the thrust, whatever be its date, drove eastward a sheet of Aptian rocks over deformed younger Cretaceous formations. " The nappe itself has been repeatedly folded and faulted and occurs mainly as remnants preserved in synclines," which now, however, form the summits of mountain peaks, including the towering Hikurangi.

In the cores of the anticlines in the New Zealand region drilling has revealed the presence of basement rocks at unexpectedly high levels. Because of the thinning and cutting out of potential reservoir formations, drilling in the anticlines has failed to locate oil pools; but in future the search may be diverted to anticlinal flanks, where stratigraphic traps of various kinds may be present.

The association of conformable with interrupted successions of Tertiary formations in closely adjacent areas is satisfactorily explained by Macpherson's theory; and successful correlations of sedimentary series in separate basins lead to the conclusion that the intermittent movements (" orogenies ") described have not been local or sporadic, but have been synchronous throughout the region.

Some, though not all, of the progressively growing anticlines of Tertiary times have become horsts and asymmetrically faulted ranges in the end-Tertiary paroxysm, which the author regards as the culmination of an era of embryonic anticlinal development. Little faulting seems to have accompanied the earlier folding.

C. A. C.

GEOLOGICAL MAGAZINE

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Gala-Tarannon Beds in the Pentland Hills, near Edinburgh.

By ARCHIE LAMONT, Grant Institute of Geology, University of Edinburgh

THERE are three main inliers of Silurian rocks in the Pentland Hills :—

(1) Lyne Water—North Esk Reservoir Inlier, which includes the Gutterford Burn section with the well-known Eurypterid and Starfish beds and the Deerhope and North Esk sections in which there is a passage upwards into red beds often referred to as " Downtonian ".

(2) Bavelaw Castle Inlier, with beds of an age similar to those in the Gutterford Burn.

(3) Loganlee Reservoir Inlier, yielding a few graptolites in strata partly corresponding with those of the Bavelaw Castle Inlier, and with an important assemblage of Silurian corals in the overlying Lower Old Red Sandstone conglomerate.

As shown by John Henderson and D. J. Brown the Gutterford Burn beds are older than those farther north-west in the upper reaches of the North Esk and in its tributaries the Deerhope, the Wetherlaw Linn, and the Henshaw Burn (1870, Pl. VIII). But it is also true that there is faulting, probably of a transcurrent nature, between the Gutterford and North Esk sections. One fault can be seen cutting the east bank of the North Esk reservoir and running approximately W. 41° N. If one attempts to make allowance for such faulting, it may well be that the Gutterford Burn beds do not lie quite so far below the fossiliferous beds in the North Esk as might appear from the map.

From recent field-study and a consideration of the extensive literature about the Silurian faunas, one may now claim that the horizons represented are earlier than has been realized. The new synchrony proposed is mainly with the Gala-Tarannon. To some extent this view revives John Henderson's opinion (1880, p. 356), which he formed after his first examination of the Eurypterid bed

and associated strata in the Gutterford Burn. These he believed were " at least as low as the Wenlock Shale ". He continued, however, to regard the beds in the North Esk as " undoubtedly Wenlock ". But it will be shown below that these beds contain a good number of shelly species which compare with forms from the Stockdale Shales of Westmorland (Marr and Nicholson, 1888) and from the high Upper Valentian described in the *Wrexham Memoir* (Smith and Wills, 1927, vol. i, p. 56). It is worth noting that F. W. Shotton (1935, p. 661) includes the bottom part of the Brathay Flags—at least of the Cross Fell inlier—in the *Monoclimacis* [1] *crenulata* Zone of the Gala-Tarannon, and not in the Wenlock. J. Wilson (1890, p. 115) and B. N. Peach (1900, p. 387) specially emphasize the importance for future research of the Gala Series in Scotland ; and the present paper tries to throw new light on the extent of this somewhat neglected formation.

All the Pentlandian species are not discussed here, but only a representative selection. Many are new to science, and formal descriptions of these are being prepared.

(*a*) *Spongiae*

Amphispongia oblonga Salter, from the North Esk, does not seem to have been recorded elsewhere. The associated sponge—*Plectoderma scitulum* Hinde—has been tentatively identified, however, by H. P. Lewis (1940, pp. 22–3) from the Pen-y-garnedd Shales which seem to reach as high as Bancroft's Onnian (Shackleton, 1938 ; Bancroft, 1945). An entire young *P. scitulum* is vase-shaped without constrictions, and resembles *Cyathodictya reticulata* Walcott from the Utica Slate of New York, but has less regular reticulation. It shows advance towards *Calathospongia* Hall and Clarke, in possessing horizontal spicular bundles. Hinde errs in treating the fascicular groups of rays as vertical.

A Receptaculitid referred to *Ischadites* aff. *antiquus* Salter is also present, with spicular plates more transverse than in the Wenlock *I. lindstroemi* Hinde and *I. koenigi* Murchison. It may compare with a similar species in the Llandovery and Gala near Girvan.

(*b*) *Conulariae*

Large well preserved *Conulariae* from the Gutterford Burn may be referred to *C. cancellata* Lindström and to *C. laevis* Lindström. The form from the Deerhope attributed by Slater (1907, p. 34, pl. iv, fig. 11) to the Ludlow species *C. subtilis* Salter, may be treated as an early mutation of that long-range stock.

[1] In this paper the terms *Monoclimacis* and *Spirograptus* are employed as in recent work by A. Přibyl and others. Lapworth and English workers have preferred to include such genera or subgenera in *Monograptus*.

(*c*) *Anthozoa*

Lists of corals from the Pentlands have been given by R. Etheridge, Jnr. (1874c) and by Nicholson and Etheridge (1878, fasc. i, p. 33) as well as in Peach and Horne (1899).

Tetradium peachii Nich. and Eth. seems to have its closest affinity with a form ascribed to the same species from the Craighead Limestone (Caradocian). Comparable American forms are *T. minus* Safford from the Trenton of Tennessee and *T. approximatum* Ulrich from the Richmond. The zoological position of *T. peachii* is, however, in doubt as Nicholson in his *Manual of Palaeontology* (Third Edition, 1889, vol. i, p. 340) includes only American species in the Tetradiidae.

The species of *Halysites* from the Pentland Hills, though smaller, bears some resemblance to *H.* cf. *labyrinthica* (Goldfuss) as described by G. W. Lee (1912, p. 257) from the Guelph, but has well preserved septal processes. Etheridge remarks on the " smaller and more circular corallites and intercalicular spaces than in either of the two British forms *H. catenularia* (Linnaeus) and *H. escharoides* (Lamarck). The tabulae are very regular and apparently more concave than in the foregoing species " (1874c, p. 51). Regular spacing of tabulae is a feature in other Pentland corals as well, since seasonal changes in the rate of growth are, in general, less marked than in those of the English Wenlock (cf. Ma, 1933). *H. gracilis* (Hall) of the Upper Ordovician also possesses well marked septa, but has very closely packed, more rectangular, corallites.

Heliolites aff. *interstincta* (Linnaeus) differs from the Wenlock species, according to Etheridge, in having " smaller calices and a less developed coenenchyma " (1874c, p. 51). Later Nicholson and Etheridge (1878, fasc. i, pp. 57–8) record *H. interstincta* from Mulloch Hill and Penkill in the Girvan district. Subsequently (1880, fasc. iii, pp. 241–259) they provide a most valuable discussion of septate and non-septate forms in connection with the occurrence of the septate form at Woodland Point, near Girvan. The Pentlandian species is also septate, but as it grew more slowly and shows less seasonal change than the Wenlock one, septation may indicate relatively adverse conditions, just as widely spaced tabulae indicate favourable environment (cf. Butler, 1937, pp. 91–3). All things considered, the Pentland species seems as closely related to Llandovery forms as to those of the Wenlock.

Nicholson and Etheridge (1878, fasc. i, p. 33) mention two or three species of *Favosites*. One of these has very large corallites and is referable to *F. gothlandica* (Lamarck), but another with small corallites and thick walls not showing perforation may be redefined as *Angopora* aff. *hisingeri* O. A. Jones. The tabulae, if anything, are more arched

and more widely and evenly spaced than in Jones's figure (1936, pl. ii, fig. 7). A species apparently with the growth habit of *F. cristata* Blumenbach is also present, and a badly recrystallized *Favistella* with some septa reaching the centres of corallites as in *F. alveolata* (Goldfuss) of the Stones River to Richmond formations in North America.

Nicholson and Etheridge had a specimen—missing unfortunately like many others—which they ascribed, with a query, to *Plasmopora petaliformis* Lonsdale. While this identification cannot be checked, it is notable how often Pentland corals approach, but do not coincide with Wenlock ones.

No record has been made of it previously, but there is a poorly preserved *Syringopora* cf. *bifurcata* Lonsdale in the Hardie of Bavelaw Collection at the Royal Scottish Museum. It has relatively fewer calices than the Wenlock one. A cast of what seems to have been a colony of *Aulopora* sp. has been found with the Dendroidea in the Gutterford Burn.

In the Limestone band at the Gutterford Burn there are species of *Streptelasma* not unlike Upper Llandovery forms, and also *Omphyma* sp. with dilated septa. The most abundant simple coral is a new species probably of *Porpites*, with fewer septa and less approximation to radial symmetry than in the Wenlock *P. porpita* (Linnaeus). Sadly for possible comparison, records of *P. porpita* from Llandovery horizons have not been confirmed by figures (Lang and Smith, 1927, pp. 486–7).

(*d*) *Stromatoporoidea*

The Gutterford Burn beds have yielded one specimen referable to *Clathrodictyon striatellum* d'Orbigny. This is common in the Wenlock, but from the stratigraphical point of view it is significant that Nicholson records it also from the Borkholm beds at the base of the Silurian (Lamont, 1935, p. 303) in Estonia. Lapworth (1870, p. 52) suggests its presence in the Abbotsford Flags of the Gala Series, near Galashiels. When he left Scotland, Lapworth ceased to work in this area.

(*e*) *Graptolithina*

The three species of graptolites that were chosen by O. T. Jones (1929) as typical of the Silurian of the Pentland Hills, were *Monograptus priodon* (Bronn), *Monoclimacis vomerina* (Nicholson), and *Retiolites geinitzianus* (Barrande). The first and last determinations may be accepted, but *M. vomerina* cannot be accepted without qualification. In the Loganlee beds the present writer thought the specimens more like *M. crenulata* (Törnquist). Dr. Bulman has confirmed this and has also identified a number of specimens from fine grits in the Gutterford Burn as *M. crenulata*. With the latter was a spiral,

unbranched species possessing somewhat long and narrow thecae, which suggested identification as ? *Spirograptus* cf. *spiralis* (Geinitz). It was found among uncatalogued material in the David Hardie collection in the Royal Scottish Museum, and may be the original of Peach's " *C. murchisoni* ? (Carruthers) " (1899, p. 593). This revision of the critical graptolites indicates that O. T. Jones's correlations with different parts of the Wenlock and Ludlow formations (1928, Appendix I; 1935, Table 3) are not acceptable, at least so far as the Gutterford Burn and Loganlee beds are involved.

The Wenlock-Ludlow correlations descend from the earliest workers —especially Archibald Geikie, who, in mapping the Pentlands, advanced downwards from the Old Red Sandstone. His conclusions were underpinned by hurried determinations of graptolites by Lapworth (1874) and by the revisory work of Peach and Horne (1899). Lapworth included " *Monograptus flemingii* " and " *M. colonus* var." in his list of specimens from the Loganlee inlier; but, to do justice to the master, it must be pointed out that the specimen of " *M. flemingii* " was a tiny fragment, seen in the field, and lost before it could be forwarded for laboratory study, while Lapworth himself explains that the specimens recorded as " *M. colonus* var." might be the same as *M. griestoniensis* (Nicol) or *M. vomerina* (1874, pp. 373–6).

Mr. Andrew Turnbull has given great help in searching for the original specimens in the Henderson collections in the Royal Scottish Museum, but the fragment from Loganlee described by Lapworth as " *Cyrtograptus scoticus* " has not been found, nor has Henderson's " graptolite which resembles *Monograptus galaensis* " from the Gutterford Burn (1880, p. 356). Peach and Horne (1899, pp. 593–4) do not refer to this latter determination, but it is mentioned by J. G. Goodchild (1900).

Peach does record (1899, p. 593) *Dictyonema venustum* Lapworth and *D.* (*Chondrites*) *verisimile* (Salter), but, as Dr. Bulman says of a possible specimen of the former submitted to him, the preservation of the thecal pattern in the Gutterford Burn grits is too poor for diagnosis of definite species. *D. venustum* has been split up into three species by Bulman (1928) all found in the Llandovery at Woodland Point, near Girvan; and Lapworth's records of it from Wintershope, at the head of the Megget Water, and Williamhope, in the Gala country, as well as from Devil's Bridge, east of Aberystwyth (1881, p. 172), suggest that the form from the Gutterford Burn may be of Valentian affinities.

The Gutterford Burn also yields Acanthograptids, among which Dr. Bulman has identified two apparently different species of *Coremagraptus*. There is also another very poor specimen in the Grant Institute of Geology which the present writer regards as having the

habit of growth of *Acanthograptus multispinus* Gurley (Bassler, 1909), albeit larger and with fewer " spines ". The degree of regularity in the arrangement of the latter cannot be properly assessed, but it is hoped that further specimens will be obtained.

It must be emphasized that there is no evidence of exclusively Wenlock graptolites in the Pentland Hills, though Macgregor and MacGregor (1936, p. 15) repeat the record of " *Monograptus flemingii* ". Indeed, the graptolite evidence now outlined suggests a horizon below the Lower Wenlock. In terms of the Tarannon area in North Wales (Wood, 1906), the likely correlation is with the Dolgau Beds which at lower levels have maroon muds like those of the Upper Llandovery Purple Shades in the West Midlands of England and also like the purple beds east of the North Esk reservoir and in the lower part of the Gutterford Burn, which include thin sandstone layers and seem almost without fossils. A possibility exists that the North Esk-Deerhope beds may occupy an intermediate position between the Dolgau Group and the Nant-Ysgollon Shales, which contain *Cyrtograptus murchisoni.* Only graptolites have been recorded in the Tarannon area by Wood, so that one does not wish to be dogmatic about the position of the North Esk-Deerhope beds which have a fauna of brachiopods, mollusca, trilobites, etc. Nevertheless many of these are common to the Gutterford Burn beds, and it seems reasonable enough to keep the higher beds of the Pentland Hills Silurian near the Zone of *Monoclimacis crenulata.* Incidentally that is the zone including purple and green shales which was originally term " Tarannon " by W. T. Aveline during his mapping in Central and North Wales. In Scottish terminology one may follow Lapworth in calling the Tarannon Series the Gala, as distinguished from the Birkhill or Llandovery Series below it.

O. T. Jones (1935, Table 3) equates the Dolgau Beds and certain beds below them forming part of the Tarannon Series of Wood with the Upper Llandovery. In the main area of the Southern Uplands he puts the Hawick, Gala, and higher Birkhill beds into his Upper Llandovery (which he calls " Llandoverian "), and in the Girvan district he compresses the Drumyork, Bargany, Penkill, and part of the Saugh Hill Group into the same division. The present writer does not believe that the Upper Llandovery beds of England and Wales reach so high as Jones imagines in the Scottish sequence. Whether they extend as high as he thinks in the Wrexham and Tarannon successions is also doubtful. An independent line of evidence may be derived from some brachiopods recently described (Lamont and Gilbert, 1946). One of these is *Dolerorthis reedi* Lamont, from the Penkill Group at Girvan, which seems to occupy an intermediate position in a possible lineage connecting *D. psygma* Lamont and Gilbert (holotype

from the *Pentamerus-laevis* beds of the Upper Llandovery, at Gunwick Mill, near Alfrick, Worcestershire), with the well-known *D. rustica* (J. de C. Sowerby) of the Wenlock. Another point is that *Platystrophia mimela* Lamont, from the Worcestershire Upper Llandovery, is found in the lower part of the Saugh Hill Group at Girvan (Reed, 1917, pl. viii, fig. 24). Jones (1928, 1935) was almost certainly wrong to put these beds in his Lower " Llandoverian ". Both at top and at bottom, he places his Upper " Llandoverian " too high in the Girvan succession.

(*f*) *Brachiopoda*

If we consider the age of the Pentland Hills succession from the point of view of the brachiopods, we note that characteristic Upper Llandovery species like *Pentamerus laevis* J. Sowerby, *Coelospira hemispherica* (J. de C. Sowerby), and *Dolerorthis psygma* Lamont and Gilbert, are absent. Similarly typical Wenlock species, which thrive in coastal silty environments, like *Strophonella euglypha* (Hisinger) and *S. funiculata* (McCoy) are not represented. But a single specimen of *S. penkillensis* Reed has been obtained, which hitherto was only known from the Penkill Group at Girvan. *Strophomena antiquata* (s.l.) as figured by Davidson (1871, pl. xliv, figs. 7–9 ; 1873, pl. 2, figs. 21–3) occurs in the Pentlands, in a mutation which looks more like specimens from the Wenlock than like those from the Upper Llandovery. The late B. B. Bancroft did some much needed revisory work on this group, but unhappily, so far as is at present known, left only a few notes on the forms he had examined. It may also be remarked that *Navilkinia* (?) cf. *groenlandica* Poulsen, a species whose external morphology compares with " *S. antiquata* " as recorded by Davidson (1871, pl. xliv, fig. 5) from the Llandovery (?) of Penkill, appears in the Hardie Collection from Gutterford Burn. *N. groenlandica* is from the Offley Island formation (Middle Clinton = Upper Birkhill), and probably a little older than the Gala-Tarannon of the Pentland Hills, if we accept Poulsen's correlation table (1941, p. 9).

Many specimens of *Schuchertella applanata* (Salter) from the Pentlands are indistinguishable from the same species in the Purple Shales facies of the Upper Llandovery in England, but some have a wavy type of costae which distinguishes them. There is also a small form referable to *Schuchertella*, in which the hinge-line does not terminate in acute-angled " ears " and which may be classified as *S.* cf. *subplana* (Conrad). Records of *S. pecten* (Linnaeus) from the North Esk, should be altered to *S.* aff. *pertinax* Reed, as they resemble that Saugh Hill species. The North Esk forms, however, never have dental plates enclosing more than a right angle.

Examples of *Leptaena* cf. *rhomboidalis* (Wilckens) and *L.* cf. *depressa*

(J. Sowerby) are abundant, but tell us little of stratigraphical interest, except that the species described by Cowper Reed (1917) from the Penkill Group, for which the name *L. zeta* is now suggested, is absent.

Upon individuals of *Plectodonta* from the Pentlands, which he examined in preparing his monograph on "*Plectambonites* and Some Allied Genera", O. T. Jones (1928, p. 448) makes the significant comment :—

> "The form from the Pentland Hills figured by Davidson [1871, pl. xlviii, figs. 3, 6–9] as *Leptaena transversalis* is hardly distinguishable from this variety [*Plectodonta millinensis* var. *canastonensis*] but it differs in several respects from *Sowerbyella transversalis.*"

Jones does not discuss the stratigraphical implications of his comment. *P. millinensis* var. *canastonensis* belongs to the Upper Llandovery in South Wales (Jones, 1928, p. 447), and closely similar specimens appear at about the same level in the Upper Llandovery of Worcestershire (Lamont and Gilbert, 1946, p. 659). Jones does not refer to the later illustrations by Davidson in a palaeontological memoir issued by the Geological Society of Glasgow (1873, pl. 3, figs. 8–13), or the earlier ones by Salter in the original *Edinburgh Memoir* (1861, pl. ii, figs. 8–9). Davidson's illustrations fail to be self-consistent. Thus the exterior of a ventral valve (1873, pl. 3, fig. 10) has two or three threads between each pair of radii, but the similarly shaped shell figured earlier (1871, pl. xlviii, fig. 3*a*) has five threads between stronger radii. Like variation in ornament, however, has been noticed during field collecting. Both of Davidson's shells have the *S. transversalis* type of outline, and the same is true of Salter's cast of a ventral interior (1861, pl. ii, fig. 9), but not of the exterior of another specimen (1861, pl. ii, fig. 8) more resembling *P. millinensis* var. *canastonensis*, or even the Lower Llandovery *P. mullochiensis* (Reed). Certain individuals of *P. mullochiensis* have a median ridge in the interior of the ventral valve, very like that seen in many specimens from the Pentland Hills, especially those from a layer a few feet below the *Harpes domina* horizon, north-west of where the Wetherlaw Linn debouches into the North Esk. Not quite so strong a median ridge is shown in some of the illustrations (Salter, 1861, pl. ii, fig. 9 ; Davidson, 1871, pl. xlviii, fig. 9*b*, and 1873, pl. 3, fig. 12). Since each of these drawings indicates a slight geniculation of the shell—an unusual feature—one wonders whether they are all taken from the same specimen in spite of minor differences in the lithography. Possibly a number of varieties exist in the Pentlands, belonging to one or two new species, and statistics are needed to discriminate which are most characteristic of certain beds. Most examples suggest relationship

with Llandovery species rather than with *S. transversalis* of the Wenlock or with *S. penkillensis* (Reed), though unfortunately the brachial interior of the latter is still unknown.

Some of the references to " *Chonetes striatella* " in geological papers about the Pentlands probably are based on specimens of *Plectodonta* with two or three strong pustules on each side of the median line and close to the hingeline. But small specimens belonging to the genus *Chonetes* do appear to be present, and have affinities with Niagaran species. There is also one which compares with *C. piperi* Moberg and Grönwall, but the Pentlands species has longer spines, more like some Czech forms such as *C. margarita* Barrande and *C. soror* Barrande (1879, pl. 46, figs. v and vi). *C. cresswelli* Chapman from the Silurian of Australia is also comparable The shell figured as *C. striatella* (Dalman) by Davidson (1871, pl. xlix, figs. 25, 25*a* ; 1873, pl. 3, figs. 14, 14*a*) seems too small for that species.

One of the most striking of the Pentland Hills brachiopods is the large *Rhipidomella* (?) *polygramma* (J. de C. Sowerby) var. *pentlandica* (Davidson). It is an index fossil of the Upper Llandovery and the Gala-Tarannon. O. T. Jones records it in the *Haverfordwest Memoir* (1914, p. 106) from the Uzmaston beds ; and Peach and Horne (1899, p. 547) record it—at least as *Orthis polygramma*—from the Bargany Group, near Girvan, as well as from the Pentland Hills.

Likewise with the distinctive " *Rhynchonella* " *pentlandica* Haswell, which is abundant in the Henshaw Burn in the higher part of the North Esk section. Its nearest British relation is *Catazyga haswelli* Reed from the Millin Stage (Uzmaston and Canaston horizons = Upper Llandovery) of Haverfordwest.

Reference has been made above to an Atrypid—*Navilkinia* (?) cf. *groenlandica*—from the Gutterford Burn. *Atrypa reticularis* (Wahlenberg) is common in all the sections. Well grown individuals from the North Esk section usually show a short but distinct median septum in the dorsal valve—a feature possibly of some value in indicating a post-Llandovery age.

Cyrtia exporrecta (Wahlenberg) from the Pentlands is very close to members of the same species from Penkill.

Other brachiopods like *Pholidops implicata* (J. de C. Sowerby), *Skenidium lewisii* (Davidson), *Nucleospira pisum* (J. de C. Sowerby), *Wilsonia davidsoni* (McCoy), and *W. wilsoni* (J. Sowerby)—not the large form—are of less value for zonal purposes.

One might expect the same to be true of the Pentland Lingulids, most of which are still unfigured. In a broad way two " circuli " of specimens might be grouped under *Lingula lewisii* J. de C. Sowerby and *L. symondsii* Salter respectively. These species are both cited from the Penkill Group by Cowper Reed (1917), but mutations are

probably present. Some of the Pentland specimens of *L.* aff. *lewisii* are distinguished from those figured by Davidson (1866, pl. iii, figs. 1–6) by larger size and by the very fine concentric growth-lines branching and arching forwards, as it were in flounces. Other specimens are more rounded in outline anteriorly and have less parallel sides than *L. lewisii* forma typica, though the proportions of length to width lie within the limits of variation assigned to *L. lewisii* by Davidson. A specimen of *L.* aff. *symondsii* Salter from the Gutterford Burn (Hardie Collection) is narrower than the example figured by Davidson (1883, pl. xvii, fig. 23). The " shoulders " in the Pentland and Penkill varieties extend very far forward and meet posteriorly in a smaller acute angle than in the typical English Wenlock and Ludlow forms. Although some of the English specimens have long " shoulders ", almost always they are more oval than the Scottish examples. Probably a new specific name should be given to the Pentland form and to Reed's specimens (1917, p. 807) from Woodland Point, Penkill, and Bargany Pond Barn.

Lingula cf. *lata* from the North Esk (Davidson, 1866, pl. iii, fig. 47) is smaller than the typical *L. lata* J. de C. Sowerby from the Lower Ludlow, and is not easily distinguishable from the Ordovician *L. brevis* Portlock. A Gutterford Burn representative is twice as long as the figured North Esk one, but has approximately the same proportions—length 14 mm., width 8 mm. This is rather like *Lingulasma tenax* Reed from the Saugh Hill Group—probably Upper Llandovery—but has no indubitable granulation of the surface and the " shoulders " meet at more than a right angle.

(g) *Echinodermata*

Some ten species of Asteroidea, from different localities in the Gutterford Burn, are worth discussing. Several of these cannot be used as zonal indices. One of the commonest—*Furcaster leptosoma* (Salter)—belongs to a " species " recorded by W. K. Spencer (1925, p. 320) from horizons ranging through the Ashgillian of Girvan, the Gutterford Burn beds, the Rochester Shale (Middle Silurian—or ? Chicotte—of U.S.A.), the English Lower Ludlow, the German Lower Devonian, and the English Lower Carboniferous. Incidentally, perhaps owing to poor labelling of the specimens, Dr. Spencer localizes the Pentland Hills in Ayrshire, instead of in the Lothians. When he comes to the related *Protaster sedgwickii* Forbes, he finds examples of it in the Middle and Upper Silurian, but does not deal with the tentative record of this Kirkby Moor Flags species from the Pentlands (Salter, 1861, pp. 136–7, pl. ii, fig. 4), although he does discuss a specimen, much larger than the type, from the " Silurian of Scotland " (Hunterian Museum E. 4515). The material may be a green grit from the Southern

Uplands or Lake District. The specimen bears seven or eight letters in faded black ink.

Pentland Hills starfish which do not show near affinities with species from other areas include *Protactis wenlockensis* Spencer, *Taeniactis wenlocki* Spencer, *Lepyractis nudus* Spencer, and *Crepidosoma wenlocki* Spencer.

Schuchertia wenlocki Spencer from the Pentlands has kinship with Trenton, Richmond, and Girardeau species—i.e. Middle Ordovician to basal Silurian—in the United States. *Mesopalaeaster* (?) sp. Spencer belongs to a mainly Ordovician genus, though *M. granti* (J. W. Spencer, 1884, pp. 53–4, pl. 7, fig. 1) comes from the Upper Clinton—probably Gala-Tarannon—of Ontario, while another species *M. bellulus* Billings belongs to the Middle Silurian. Another possible representative, but not closely akin to the Pentlands one, is *M.* (?) *ketleyi* Spencer from the Wenlock Limestone of Dudley. Other starfish from the Wenlock Limestone of England, like *Lepidactis wenlocki* Spencer and *Lepidaster grayi* Forbes, are not found in the Gutterford Burn.

Bdellacoma vermiformis Salter, of which the type is from the Lower Ludlow of Leintwardine, is also reported by W. K. Spencer from the Pentland Hills and from the Lower Devonian of Germany (1940, p. 529). It, therefore, is not a good index.

The case of *Urasterella gutterfordensis* Spencer is different. It has affinities with several Silurian species of the same genus. Spencer (1918, p. 145) provides the following note :—

> " It is difficult to connect this species with either *U. thraivensis* or *U. ruthveni*. At first sight it might seem to be the small beginnings of the *U. ruthveni* lineage, but the Wenlockian of Gotland . . . contains a much larger and more typical specimen of that lineage, suggesting that we must look for the roots of the lineage in older strata."

The obvious solution is now to regard the Pentland Hills beds as " older strata ".

To the known Wenlock starfish which are absent in the Pentlands, we may add the Upper Wenlock–Lower Ludlow species *Eoactis simplex* Spencer.

It is interesting that the Upper Llandovery (*Pentamerus laevis* beds) species *Salteraster* (?) *coronella* (Salter) has also not been found in the Pentlands.

One plate of a Glyptocystidean, possibly allied to an undescribed form from Bargany Pond Burn at Girvan, occurs in the Pentlands.

(*h*) *Machaeridia*

John Henderson, from some of his identifications of fossils in the Royal Scottish Museum, appears to have anticipated the views of Bather and Withers on the possible relationship of the Machaeridia

with certain Echinoderms. At least the Glyptocystidean plate mentioned above was mounted by him on the same tablet as specimens of *Plumulites* and *Anatifopsis*, and he seems to have queried the ascription of these genera to the Cirripedia. Unfortunately his notebooks were " pulped " during a wartime drive for waste paper.

The Wenlock Limestone species *Turrilepas wrightiana* (de Koninck), which has frequently been recorded from the Pentlands, has not been noted by the present writer. A species of *Plumulites* with excessively fine ornament is apparently the one figured by Haswell (1865, pl. iv, fig. 12). It will be described later. Another species is more like the Girvan Ordovician examples, and it is with it that T. H. Withers (1926, p. 70) associates the MS. name of " *T. haswelli* " Salter.

It should be remarked that there is now no record of *Plumulites* from undoubted Ludlow strata.

(*i*) *Lamellibranchiata*

The lamellibranchs of the Pentland Hills are abundant and mostly distinctive. A few forms closely related to those of other districts are material to my argument. Thus *Lunulicardium elegans* Salter (1861, p. 139, pl. ii, fig. 10), from the Henshaw Burn in the Pentlands, is also reported from the Penkill Group at Girvan (Wheelton Hind, 1910, pp. 533–4, pl. iv, fig. 23). The Girvan species, however, has finer radial ribs and less marked concentric growth-pauses. By the time the beds at the Henshaw Burn were being deposited, following uplift of neighbouring land, conditions may have been more seasonally variable than in the earlier episode represented by the limestone bed in the Gutterford Burn with its corals. Both Scottish varieties of *L. elegans* agree fairly well with *Dualina secunda* Barrande (1881, pl. 27, fig. 26), from Stage E, a species which is also reported from the Silurian of the Pyrenees by von Gaertner (1935, p. 22). The beds there are taken as Wenlock, but difficulties about correlation seem to exist. The Pentlands also yield a larger species of *Lunulicardium*, more like *D. conica* Barrande (1881, pl. 72, fig. 8) or *Maminka comata* Barrande (pl. 186, fig. 22). Its closest relationship may be with *M. tenax* Barrande (pl. 187, fig. 20) which is from Stage Ee_1 at Borek.

While one must be cautious about connections between provinces usually so separate as those of Northern and Central Europe (cf. Cowper Reed, 1910, pp. 26–7), trilobite evidence of an exchange of faunas between Scotland and Czechoslovakia in Pusgillian and early Ashgillian times is well known. A later migration is further suggested by a recently discovered specimen from the Pentlands, which has a sharply truncated anterior margin like such characteristic Czech Silurian species as *Tetinka accidens* Barrande and *Spanila gracilis* Barrande, or it may belong to *Hemicardium*. It is related to

"*Byssonychia*" *sublaevis* Wheelton Hind (1910, pl. i, figs. 25, 25*a*), from the Mulloch Hill and Saugh Hill Groups at Girvan, but is distinguished by the intercalation of short ribs close to the posterior part of the inferior margin. There are also undescribed Pentlandian lamellibranchs which resemble *Avicula glabra* Münst. (Barrande, 1881, pl. 228, fig. 4A) and *A. impar* (Barrande, 1881, pl. 229, figs. 1, 1A), as well as Ferriter's Cove types in Eire.

The Pentland *Anodontopsis lucina* Salter (1861, pl. ii, fig. 14) is close to *Lucina* ? *subquadrata* Grönwall (Moberg and Grönwall, 1909, pl. ii, figs. 22–3), but the Swedish species has fewer and less regular growth-lines. *Grammysia unilira* McLearn from the McAdam formation of Nova Scotia seems to be an ally. *A. quadrata* Salter, from the Ludlow, has many more and finer growth-lines, but differs somewhat from an unfigured large Pentlandian form.

Grammysia mcadamensis McLearn (1924, pl. x, fig. 17), from the McAdam formation, appears almost identical with a very abundant small lamellibranch of the North Esk section, which has been figured by Salter (1861, pl. ii, fig. 18) as "? *Acroculia antiquata*". The McAdam may well be of Gala-Tarannon age. Schuchert (see Twenhofel, 1909, p. 162) correlates it with the lower part of the Rochester, and finds himself trying also to associate it with both the Upper Llandovery and the Lower Wenlock. Professor O. T. Jones points out to me that in beds with related faunas both above and below the McAdam formation there are Eurypterid fragments. These have not been described by McLearn (1924), but it seems very likely that they will prove to resemble Scottish species.

Grammysia aff. *cingulata* Salter, *Orthonota* (?) *amygdalina* var. *gentilis* Salter, and *O. salteri* Haswell from the North Esk, all require more study in comparison with similar Silurian species elsewhere, before their exact stratigraphical value can be assessed. While the Pentlands species seem distinguishable enough, it is recognized that all these lamellibranchs are very variable. Judging from published figures one can say at once that *O. salteri* has less pronounced ornament than the related "*Sanguinolites*" *anguliferus* McCoy as reported from the Swedish Wenlock by Moberg and Grönwall, and that it is more elongate relatively to height than the Swedish species, or than *O. rigida* (J. de C. Sowerby) from the Lower Ludlow. But what is really wanted is a comparison of groups of specimens not of isolated individuals.

An interesting Penkill and Saugh Hill Group shell found in the Pentlands is *Goniophora antiquata* Wheelton Hind (1910, pp. 539–540, pl. iv, fig. 25—the other figures are less like the Pentland example). The specimen in the Henderson Collection at the Royal Scottish Museum is labelled with the specific name "*cymbaeformis*", and may be the *G.* "*cymbaeformis* (Sow.)" of Peach's list (1899, p. 596),

from the highly fossiliferous *Plectodonta* mudstones near the mouth of Wetherlaw Linn.

This amendment of Peach's identification may have significance elsewhere, for he also records *G. cymbaeformis* in the lower part of the Lesmahagow Silurian, in a small streamlet about half a mile east-north-east of Waterhead in the Greenock Water. No great value, however, can be attached to many of these records. For example, the occurrence of "*Mytilus mytilimeris* (Conrad)" in the Long Burn, a tributary of the Logan Water, near Lesmahagow, might mean that these beds contain *Mytilarca* (*Plethomytilus*) sp. as found in the Wenlock Limestone or Lower Ludlow (Stubblefield, 1938, p. 42), but one also notices that Wheelton Hind (1910, pp. 516–17) reports this form from the Llandovery of the Saugh Hill Group at Woodland Point, Girvan. Indeed he also says it comes from the Girvan Ashgillian, but that is a mistake. The general argument, then, from such fossils, is that since there are several thousand feet of strata in the Pentlands probably referable to Gala-Tarannon—Geikie in 1868 calculated on over 3,000 feet—and since there is also a considerable thickness of Gala-Tarannon at Girvan, just merging towards the top into Lower Wenlock, it will be a surprise if a large part of the beds in the Lesmahagow inlier, situated in an intermediate geographical position between the Pentland Hills and the Girvan district, does not also prove to be Gala-Tarannon.

It may be noted that the Lesmahagow species *Modiolopsis mimus* Salter has more affinity with *M. pyrus* Salter, from the Bala, than with known Ludlow forms (Reed, 1902).

(*j*) *Gastropoda*

From a MS. note at the Royal Scottish Museum, it appears that C. W. Peach found difficulty in distinguishing "*Platyschisma helicites*" from the Lesmahagow Silurian and "*P.*" *simulans* Salter from the Pentlands. One heartily agrees with Cǒwper Reed who tried (1901, pp. 256–7) to revive the trivial name *helicioides* given to the former by Salter (1873, p. 186, *b* 140, *c* 26). From well preserved examples it is clear that in neither case is the genus correctly described as *Platyschisma*. Some of the specimens may be nearer to *Euomphalopterus alatus* (Wahlenberg), and to an undescribed *E.* aff. *ordovicus* Longstaff from the Girvan Ashgillian.

References to *Holopella obsolets* (J. de C. Sowerby) have not been verified.

A *Loxonema* in the North Esk area has slightly less sinuous growth-lines than *L. elegans* McCoy which is the Wenlock form.

At Henshaw Burn, near the top of the North Esk succession, a new species of *Hormotoma* is fairly common. It has the band too far back

on the whorl, and has too few whorls for *H. cingulata* (Hisinger) as found in the Mocktree facies of the Aymestry Limestone, and has more affinity with Llandovery and Guelph species. Its remarkably wide spacing of the growth-lines reminds one of *Turritoma* (?) *tenuifilosa* Donald from Woodland Point. Another new species may belong to *Plethospira* or *Lophospira*, and has much the same aspect as *Omospira orientalis* Donald, from the Ashgillian.

Euomphalids with the imbricate type of ornament of *Polenmita discors* (J. Sowerby) are represented, but closer examination shows that they have too many spiral keels on the posterior sides of the whorls for the typical form of that Wenlock species. There is another species, with numerous keels on the anterior (basal) sides of whorls, which is not quite reconcilable with either Upper Llandovery or Wenlock forms, though in the past it has been grouped with *Euomphalus sculptus* J. de C. Sowerby.

Turning to the Bellerophontacea of the Pentlands, one must dismiss Peach's list (1899, p. 714) and substitute the following provisional one: *Kokenospira* cf. *euphemoides* Reed, *Cymbularia* sp. nov. with more flattened dorsum than Reed's *C.* cf. *fastigiata* (Lindström), *Salpingstoma* aff. *asteroideum* Reed, and *Bucaniopsis* (?) cf. *hybridus* (Grönwall).

(*k*) *Cephalopoda*

One of the Pentland Hills fossil groups most in need of revision is that of the Cephalopoda.

A glance at Blake's illustrations (1882, pl. vi, figs. 7–10) is sufficient to show that the specimens from the Lower Ludlow of Ledbury ascribed to *Orthoceras maclareni* Salter are probably different from the Pentland Hills species.

The wide range of ornament exhibited by examples of *Kionoceras*, and possibly *Polygrammoceras*, makes it difficult to distinguish some Wenlock and Ludlow types from those found in the Pentlands, but for a balanced approach to the problem one can consult the figures of similar species from the equivalents of the Llandovery and Tarannon in Nova Scotia (McLearn, 1924) and in Anticosti Island (Twenhofel, 1927).

Kionoceras cf. *angulatum* (Wahlenberg), it may be noted, is a common form both in the Pentlands and in the Bargany Group at Girvan, as well as in the Raeberry and Balmae area south of Kircudbright. Statistical examination of bio-characters may bring out the stratigraphical value of these fossils. Unfortunately while reporting on the earlier occurrences, J. F. Blake figured only Wenlock and possibly Ludlow examples (pl. vii, figs. 1, 3, 4, 8, 9).

Two important new species await description. One is a small haggis-shaped creature with less dorsal concavity than *O. featherstonhaughi* Clarke from the Trenton, but with the same kind of marginal

ventral siphuncle ; the aperture, however, is contracted as in *Mandaloceras*, and the external ornament forms wide backwardly directed curves on the ventral side as in *Diestoceras*. The general aspect is like *Gomphoceras bohemicum* Barrande and *G. amphora* Barrande from Stage E. *G. deshayesi* Barrande has a marginal siphuncle, but is more elongate, and the aperture is probably more complicated—with five lobes, not three. The other new species seems, in the past, to have been referred to *Phragmoceras compressum* J. de C. Sowerby, of the Ludlow formation. The Pentlands species has far fewer septa and is also singled out by a very well preserved tubular projection of the shell around the exhalent funnel. One example from Gutterford Burn collected by the present writer shows closer affinities in this respect with an American species like *P. parvum* Hall and Whitfield, from the Guelph and Rochester formations, than with English forms, though comparable curvature and septal spacing are found in the Lower Ludlow *P. intermedium* McCoy and *P. arcuatum* J. de C. Sowerby. The Czech *P. imbricatum* Barrande and *P. labiosum* Barrande from Stage E show the same elongation of the funnel.

(*l*) *Hyolithidae*

The Hyolithidae appear to include one species of each of the genera—*Hyolithes*, *Ceratotheca*, and *Pterotheca*. The *Hyolithes* has ornament recalling that of *H. sylvestris* Reed from the Saugh Hill Group, but the shell tapers more slowly than in that species so that in gross morphology there is greater resemblance to the Balcletchie (Caradocian) species *H.* (*Orthotheca*) *subexcavatus* Reed. The *Ceratotheca* is very small, smaller than *C.* (?) *balclatchiensis* Reed, and very much smaller, as well as less curvate, than *C.* (?) *subuncata* Reed which is the Penkill form.

A very fine specimen of *Pterotheca*, in the Hardie of Bavelaw Collection, shows closest resemblance to *P. drummuckensis* Reed (1909, pl. iii, fig. 5), but the concentric rugations are strongest at about half the length of the shell, and it is also notable that anteriorly the lateral angulations are obsolete, a condition recalling that seen in *P. mullochensis* Reed (pl. iii, fig. 18), in which, however, the median carinated fold and the rugations are more reduced than in the new Pentland Hills species. *P. consobrina* Barrande from Stage Dd 5 is also fairly close, but does not show anterior failure of the lateral ridges. Anterior failure in these ridges suggests the presence of a platform analogous to that in *Crepidula*, as demonstrated in *Pterotheca expansa* (Emmons) from the Black River beds. The same failure is also seen in the genotype, *P. transversa* (Portlock) from the Ashgillian of Co. Tyrone.

(*To be continued.*)

The Granite Controversy

By Doris L. Reynolds

THIS year, the 150th anniversary of Hutton's death, we are particularly reminded of the lively struggle of the eighteenth century between Vulcanists and Neptunists ; the more so since that struggle finds its counterpart to-day in the divergence of opinion between two schools of petrology whose respective members might aptly be called Magmatists and Transformists. Much of the disagreement between the modern opponents arises from a belief on the part of the Magmatists that Hutton proved the magmatic origin of granite, and, in addition, the disagreement is probably strengthened by a misunderstanding of the views held by Transformists, and by lack of knowledge or experience of the evidence on which they base their conclusions. Indeed, Transformists might be tempted to preface their writings with the following very apposite quotation from Werner (1781) :—

> " I must here present a request to all who would judge of this theory, or communicate their sentiments on it to the public, viz. to begin by reading through the whole treatise, and then to peruse it a second time, with attention. Such a request will not only appear strange to many persons, but even superfluous ; I find myself, however, under the necessity of making it from the manner followed by some individuals with my book on the external characters of fossils. They have often represented me as saying quite the contrary of what I have expressly written. This may have been done by some, through design, but in by far the greater number of instances, it has happened from that work not having been read through ; and in this manner the public has frequently been led into an error, at least for some time."

Two or three examples will suffice to show that misrepresentation of this kind is still common. In a recent review of the evidence relating to the formation of igneous-looking rocks by metasomatism, written with the highly commendable object of developing reliable criteria, it is disappointing to find that Grout (1941), instead of presenting his case fairly and objectively, systematically attempts to discredit those who advocate the importance of metasomatism and rheomorphism by leading his readers to suppose that they have done so without due regard to the relevant evidence. Thus, in the course of a paragraph which begins : " Many writers state that there is evidence but do not give the evidence to their readers," Grout writes (1941, p. 1565) :—

> " Reynolds (1934, p. 596) says ' the evidence of the origin of the fused sediment is to be found in the wall of the intrusion ', but few of the readers can look carefully at that wall ; and elsewhere (1937,

p. 258) that 'the evidence of replacement is striking', though not saying what the evidence is."

In the first of these examples the sentence quoted by Grout is merely the introduction to a two-page presentation of the actual field evidence. Petrographic and chemical support follow on later pages. In the second example—misquoted by Grout—the evidence is presented in a photomicrograph and its description to which the reader was referred. Moreover, this is only one small illustrative item in a paper which is largely devoted to a description of the evidence that the Caledonian granodiorite of Newry is metasomatically transformed to granophyre (with change of composition) at its contact against Tertiary gabbro.

On p. 1548 Grout makes the following statement :—

"Reynolds (1936) described some quartzite xenoliths at Kiloran Bay, and Holmes (1936) some quartz xenoliths in lavas of Uganda, and both seemed to think the evidences of replacement were so clear in the field that no more proof was needed."

Again the criticism is entirely unmerited, as reference to the original papers will show. Suffice it here to say that in the case of the quartz xenoliths from Uganda no evidence of replacement was, or could have been seen in the field ; the evidence is entirely microscopic and chemical, and was obtained from specimens supplied by the Geological Survey of Uganda. Nothing could be further from the truth than Grout's implication that Holmes and Reynolds thought detailed proof of replacement so unnecessary that they failed to provide it. The fact is that in both these papers every possible kind of evidence is fully presented, indeed the papers had no other purpose. The same paper of Grout's contains other misleading statements and ill-founded criticisms concerning work on petrogenesis both by myself and several of my geological friends.

A further example of misrepresentation appears in a recent letter by Tilley (1947, p. 119) where, with reference to a discussion of the origin of Cornish greenstones and cordierite-anthophyllite rocks, he writes :—

"conjuring with von Wolff diagrams, ill suited for the purpose, provides, it seems, the real enlightenment, here as elsewhere."

There is no "conjuring" either in the paper (Reynolds, 1947) to which Tilley refers, or in any other in which I have used von Wolff diagrams. The latter are no more than representations of the chemical analyses of the rocks concerned, as was made quite clear in the paper on the Cornish greenstones, where it was stressed that

"the diagram merely indicates chemical relationships, and cannot in itself be used to solve the problem of the origin of the rocks, the solution of which must rest in a correlation of field, mineralogical, and chemical evidence."

Moreover, it was further stated that

> "The present paper, offering tentative interpretations of some of the Cornish rocks, is written in the hope of focusing attention on the petrogenetic significance of the region, and thus of stimulating detailed investigations, with strict correlation between field observations and chemical analyses, by which means alone the problems presented can be solved" (Reynolds, 1947, p. 33).

In the group of natural sciences to which geology belongs, advances are made by means of interpretations based on observations, due respect being paid to current physico-chemical knowledge. It sometimes happens in the natural sciences, however, that observed phenomena suggest the operation of physico-chemical processes that may be unfamiliar or even otherwise undetected at the time. Thus Hutton's recognition of unconformities and of veins extending from masses of granite into the surrounding schists, led him to infer the existence of a source of heat adequate to give rise to magma, and to raise mountain ranges. This deduction was made in advance of the discovery of radioactivity. It was, therefore, without the support of an acceptable explanation of the source and maintenance of the necessary heat, and in consequence led to attacks from the Neptunists of which the following is an example :—

> "So far, therefore, the improbability of this principle of the Huttonian theory, that fossils [rocks] have been fused by a subterraneous heat, must appear evident from the difficulties which attend it. Whether we consider the extent of the strata thus supposed to have been fused, or the extreme infusibility of the matter of which they are composed, the heat requisite must exceed, in intensity, not only any that we know, but even any that the imagination can conceive ; and for the production of such a heat, no adequate cause can be assigned." (John Murray, 1802, p. 35).

But, as Playfair (1802) truly wrote in defence of the Huttonian theory :

> "We are not entitled, according to any rules of philosophical investigation, to reject a principle to which we are fairly led by an induction from facts, merely because we cannot give a satisfactory explanation of it."

The recognition of granitization and associated basic fronts leads to inferences that once again imply the operation of unfamiliar physico-chemical processes. Such inferences are, therefore, readily susceptible to criticism. Tilley, however, does not even offer criticism, but writes :—

> "I do not propose to dwell further on so gross an error—it may well be left to seek its own level in the heavy score of misrepresentations already standing to the credit of 'front' petrology" (Tilley, 1947, p. 119).

This is merely authoritarian bluff of no scientific interest.

Stated briefly, without reference to the manifold evidences on which the conclusions are based, the Transformist view is that the field evidence is, in many instances, adequate to prove that the formation of granite can take place by the transformation in situ of pre-existing rocks. Such transformation has been brought about as a result of chemical change dependent on the introduction of certain constituents, including alkalis, and the removal of others. Since the rocks undergoing transformation to granite (commonly argillaceous sediments with intercalations of limestone, sandstone, and basaltic rocks) are generally in bulk more basic than granite, the displaced constituents are usually rich in Fe, Mg, and Ca. These emigrant constituents become fixed in the " basic fronts " of granitization (see Reynolds, 1947), and may give rise to " igneous " rock varieties more basic than granite. Transformists do not deny, indeed they actively maintain, that the processes of transformation may, under appropriate conditions of pressure, temperature, etc., lead to the formation of magma: many lavas and hypabyssal intrusions, other than basaltic, may have their origin in magma generated in this way. For such mobilized rock material Backlund (1936) proposed the term *rheomorphic*. The word means " flow form ", and signifies that some pre-existing rock, whether initially sedimentary, plutonic, metamorphic, or volcanic, has acquired from the solid state sufficient fluidity to become eruptive as a result of chemical changes and rise of temperature. Thus from solid diorite rheomorphic andesitic magma may be generated.

With regard to the supposed evidence for the magmatic origin of granite, it is well to re-examine exactly what Hutton did prove. Having correctly interpreted basaltic rocks as of volcanic origin, Hutton was impressed both by the lack of stratification in granite, and by its crystallinity. These criteria led him to infer that granite, like basalt, had crystallized from a state of fusion. He then deduced that if this were true, it would be possible to find examples of granite penetrating the adjoining rocks, and, for this express purpose, he set out to examine the granites of the Grampian Highlands. In Glen Tilt, as is well known, he did find veins of granite proceeding from a granite mass into the adjoining mica-schists and limestone, and so great was his joy at this discovery that his attendants thought he must have discovered gold. The majority of geologists have unquestioningly accepted the evidence of such veins as adequately establishing the magmatic origin of granite, since the interpretations of Neptunists and Vulcanists seem to exhaust the possibilities, and the Neptunist view was shown to be untenable. In the eighteenth century crystallization either from aqueous solution or from molten rock material would be the only

processes that could, with any degree of scientific background, be envisaged for the origin of granite. During the present century, however, solid diffusion has become a well known physical process, and it is, therefore, now necessary from the philosophical aspect alone to add a third possibility concerning the origin of granite: it may have resulted from recrystallization in the solid state in response to change of chemical composition brought about by solid diffusion and rise of temperature. Thus, a little reflection reveals a fallacy in the argument for a magmatic origin of granite based on the evidence of veins. At most, all that is proved by Hutton's evidence is that the veins themselves represent magmatic material. From the recorded evidence relating to the veins in Glen Tilt three interpretations are possible. (1) The granite may have been emplaced as magma. (2) The granite may have been formed in situ as a result of chemical transformation of the pre-existing rocks under conditions of rising temperature with at least partial rheomorphism. On this view the veins would represent rheomorphic material that penetrated fissures in the adjacent rocks. (3) The granite and the veins may result from transformation, in situ, of pre-existing rock, without rheomorphism. A careful re-examination of the Glen Tilt occurrence is necessary before any conclusion can be reached as to which of these three possibilities represents the correct interpretation of that particular case. Wherever they occur, granite veins similarly fail to prove that the main body of granite from which they emerge was emplaced as magma, or that it once existed in a wholly magmatic state. We have direct knowledge, based on observation, that lava crystallizes from a molten condition, but the supposition that plutonic rocks represent the crystallization of magma is, to the present day, a pure hypothesis, and a hypothesis, moreover, at variance with many observed phenomena. Its strength lies in familiarity and usage.

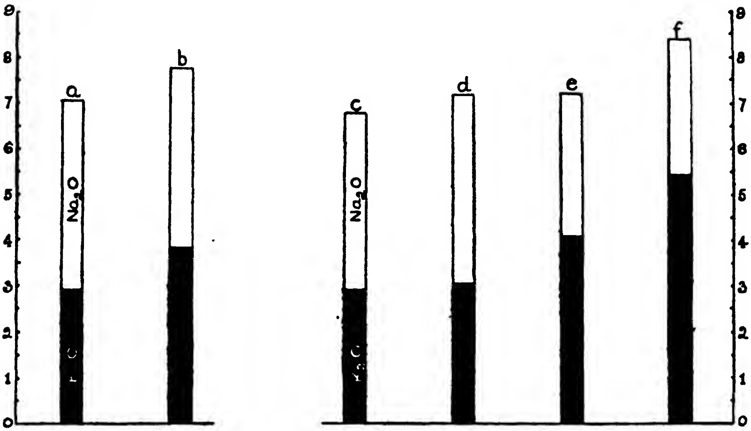
Magmatists generally regard crystal differentiation as the major petrogenetic process, and granite as a product of crystallization of residual magma resultant from the fractionation of a more basic parental magma. In attempting to demonstrate the supposed derivation of granite magma they commence with a hypothesis and then endeavour to show, by physico-chemical and chemical arguments, that the observed chemical and mineralogical variations in the rocks concerned are consistent with the assumed hypothesis. Thus Nockolds (1941, p. 494), in writing of the rocks of Garabal Hill, states, "Any theory of origin must *first* be capable of explaining the form of the variation diagram" (my italics). The explanation of a variation diagram is thus given "pride of place" over field criteria. Then, having selected a parent magma by reference to the variation diagram, he proceeds to ask (p. 497), "Can this *assumed* parental magma be

regarded as a suitable *choice* apart from its position in the variation diagram ? " (my italics). At best such a method can only show internal consistency ; it cannot provide proof either of crystal differentiation or of the existence of magma. In following such a method it is very easy, however, for the investigator to forget that a hypothesis is being tested, and to mislead the reader by writing as though the points at issue were already proven. Thus, in a recent letter in the *Geological Magazine* Nockolds (1947, p. 61) writes, with reference to the Scottish Caledonian rocks in general : " The facts brought forward . . . indicate a most striking similarity of behaviour between these constituents [the light constituents] in *natural magmas* and in experimentally determined melts " (my italics). If there were any means of obtaining knowledge of the behaviour of constituents in natural magmas, the work of members of the Geophysical Laboratory would surely be redundant. Step by step the reader has been led, first to a hypothesis, because it explains a variation diagram, then to a choice of an assumed parental magma, and before long the hypothetical form of the whole structure has been forgotten, and the rocks themselves appear in the guise of " natural magmas ". An even more mesmeric effect is induced by Niggli's method of describing sets of numerical quotas, calculated from chemical analyses of rocks, as " magma types ", and by the equally misleading terminology of Billings and his co-workers who prejudge the issue by describing each of various suites of rocks as " magma series ".

In a recent paper Nockolds (1947) shows that granite aplites fall on or close to the plagioclase—potash-felspar—quartz cotectic curve deduced by him from existing experimental data. He concludes (pp. 22 and 24) that this " is consistent with the generally accepted view that they represent residual liquids derived by crystallization-differentiation from a more basic magma and *it would also be consistent with the view that they were products of refusion, representing the lowest melting mixtures, if any evidence of such refusion should come to hand. But it does not appear to be consistent with the view that they have been derived directly or indirectly from the activity of emanations acting on sedimentary or other rocks* " (my italics).

Nockolds's findings are in no way inconsistent with the view that the veins under consideration may have arisen as a result of " emanations acting on sedimentary or other rocks ". In 1935 Richey described veins extending from what he took to be unaltered Newry granodiorite of Caledonian age into the Tertiary " gabbros " of the Slieve Gullion area. Later (1937) it was shown by the writer that the Caledonian granodiorite is actually considerably altered at its contact with these " gabbro " masses. The alteration appears first in the remarkable development of parallel-sided rims of fine-grained micro-

pegmatite around the quartz groups. As the alteration increases the rims become wider and the micropegmatite becomes coarser grained. As micropegmatite develops from the quartz groups, the margins of the original oligoclase crystals are replaced by potash felspar. The alteration is highly spectacular, and is illustrated in my papers (1937, 1941) by series of ten photomicrographs and a camera lucida drawing. Complete chemical analyses of the rheomorphic micro-



TEXT-FIG. 1.—Diagram showing the increase in the total alkalis, and in the K_2O/Na_2O ratio in Caledonian granodiorite at various stages of its transformation to Tertiary granophyre.

(*a*) Newry granodiorite (1547) about 15 yards from its contact with " quartz-gabbro " east of Flurrybridge.

(*b*) Transformed Newry granodiorite, containing micropegmatite (1622), about 10 yards from its contact with the " quartz-gabbro " east of Flurrybridge.

(*c*) Hornblende-granodiorite (1726) from the western end of the Newry Complex.

(*d*) Micropegmatitic granodiorite (1541). Transformed Newry granodiorite from the south-western slopes of Slieve Gullion.

(*e*) Adamellite (1563). More advanced stage of transformation of Newry granodiorite than (*d*), from the south-western slopes of Slieve Gullion.

(*f*) Tertiary granophyre (1557), Slieve Gullion.

pegmatitic transformation products that penetrate the " gabbro " as veins were not made, but judging from the mineralogical composition of the rocks it is clear that when they are analysed they will fall close to the granite cotectic curve drawn by Nockolds. Although complete chemical analyses were not made, the alkalis were determined in three specimens of the micropegmatitic rocks (Reynolds, 1937, Tables I and II), and from comparison of these alkali determinations with those of the unaltered Caledonian granodiorite (see Text-fig. 1)

there can be no doubt that there has been radical chemical alteration. The final product of alteration of the Caledonian granodiorite, dependent on transformation in situ, and culminating in rheomorphism, is, in fact, closely similar to if not identical with the Tertiary granophyre of the region.

Nockolds's conclusions, from the evidence of his diagrams, must, therefore, be amended as follows. The compositions of granite aplites and related rocks are consistent with (1) the generally accepted view that they represent residual liquids derived by crystallization-differentiation from a more basic magma, (2) the view that they are products of refusion, representing the lowest melting mixtures, and (3) the view that they have been derived directly or indirectly from sedimentary or other rocks by rheomorphism.

Towards the end of his paper on the granite cotectic curve, Nockolds (1947, pp. 26–7) refers to aplites that are abnormally rich in soda as compared with those he has previously considered. Two of the aplites that are particularly rich in soda he finds to be richer in quartz than the albite-quartz eutectic. Of these two aplites he writes : " The other two are too rich in quartz and *must* have been produced by the albitization of ordinary granite-aplites or *possibly* by deposition from solutions as suggested by Bowen (1910, 669) and van Bemmelen (1938, 10) " (my italics). Since the main tenor of the earlier part of Nockolds's paper is to show that the chemical composition of aplites is consistent with derivation from residual melts derived by crystallization-differentiation from more basic magma, it would be easy for the reader to be misled by the sentence quoted above into believing that these soda aplites, though possibly metasomatically altered, are representatives of residual magma. It is, therefore, important to draw attention to the field evidence recorded by the original investigators (Bowen and van Bemmelen), and to the conclusions based thereon.

One of these aplites, described by Bowen, occurs in a diabase sill in the Gowganda district, Ontario. In this area diabase sills are intruded into slate which is altered to adinole along the contacts. Of the contact zones Bowen (1910, pp. 667–8) writes :—

" We have at the Foot Lake sill, in one place, the special development of granophyric material in the diabase quite close to its contact with altered slate or adinole, the granophyric interstices having practically the same composition as the adinole and evidently derived from the latter by some process of transfusion. A little farther south where the action has been more intense we have a wider zone of adinole development. Part of the adinole close to the diabase has been to some extent recrystallized, giving the beginning of granophyric structure. The writer believes that in the case of the Lily Lake and Lost Lake sills the evidence points to a

still more complete recrystallization of part of the adinole with the production of typical granophyre. *In other words, some of the adinole was essentially in a state of aqueous fusion and crystallized as granophyre.* The melt thus formed was, to a certain extent, free to diffuse into the diabase magma and give rise to the abundant granophyric interstices near the granophyre" (my italics).

Bowen attributed the transformation of slate to adinole to introduction of soda with concomitant loss of some magnesia, iron, alumina, and potash. Regarding the further change of adinole to granophyre, and finally to the aplite veins to which Nockolds refers, Bowen writes :—

"The partial analyses . . . of the altered sediment (adinole) near the Lost Lake granophyre, together with its microscopic examination, show it to be an albite-quartz rock approximating the granophyre in composition. The nearly pure albite layer . . . between granophyre (recrystallized adinole) and adinole probably separated from the fluid granophyre. Albite is certainly in excess in the granophyre (note phenocrysts) and its separation towards the adinole would be especially favoured by the composition of the latter.

"That the granophyre 'solution', formed as here imagined, was foreign to the diabase magma is indicated by the intense alteration of the constituents of the diabase near the granophyre interstices.

"The aplite veins (quartz and albite, often with calcite) which cut both granophyre and diabase were formed from the more aqueous residuum of the granophyre."

The aplite vein from the Gowganda district, Ontario, is thus in no way related to granite magma derived by a process of crystallization differentiation from basic magma, but is rather, in modern nomenclature, a rheomorphic vein derived from transformed shale.

The other example of a soda-rich aplite is described by van Bemmelen from the Merawan batholith, in the southern mountains of Eastern Java. According to van Bemmelen the hornblende-granodiorite of this batholith shows gradual transitions, both in the field and chemically, to the "Old-andesites" within which it is emplaced. The aplite vein under discussion cuts the hornblende-granodiorite close to its contact with the "Old-andesite". Van Bemmelen writes (1938, p. 10), of no part of the granodiorite in the roof region can it

"be stated with certainty, that it really has ascended as a juvenile granite *melt* (produced by crystallization differentiation of some parental magma in the depth). This would only be an assumption *ad hoc*, under the influence of the current theoretical views on fractionated crystallization differentiation.

"*It seems, therefore, more probable that the rising thin solutions*

in the migmatite front (in the sense of Wegmann) caused a progressive metamorphism and finally ultra-metamorphism (e.g. granitization)."
He adds (p. 11) :—

"It seems that in the ascending emanations zones of different composition can be distinguished (depending on temperature and pressure conditions). In this case the sodium-rich solutions reached higher levels than the potash-rich emanations."

Van Bemmelen certainly states that the veins might have been deposited from thin solutions, but the solutions to which he refers are those to which he attributes the granitization, they are not residual magmas resulting from crystal differentiation. It has, moreover, to be kept in mind that van Bemmelen was writing nine years ago. At that time there was complete uncertainty as to the processes that brought about granitization. More recent work has shown that such transformations are most easily explained as a result of solid diffusion, and it seems most probable that this is dependent on ionic migration, the sequence of migrations being to some extent controlled by ionic size. On this more modern view the enrichment in sodium (ionic radius = ·98 Å) at higher levels, and in potassium (ionic radius = 1·33 Å) at lower levels is more readily understandable ; the veins are possibly rheomorphic.

Of the two quartz-rich soda aplites which Nockolds says "*must* have been produced by the albitization of ordinary granite-aplites or *possibly* by deposition from solutions" (my italics), one, described by Bowen, is thus a rheomorphic vein of sedimentary origin, and the other, described by van Bemmelen, is possibly a rheomorphic vein. One is reminded of the following remarks of Fenner's (1937, pp. 163–4):

"I have been shown specimens of rock from the roof of the Bushveld lopolith, collected by Wright, that would generally be regarded as granites, and I am told that rocks of similar character occur in great thickness over hundreds of square miles of the Bushveld. In composition and in relation to underlying rocks they conform, to the best of my knowledge, to all the requirements that the theory of crystal fractionation asks for ; yet they were not formed in that way. In a strict sense they are not igneous rocks at all, but were produced by the granitization of sedimentary quartzites by emanations. I wonder if some of the rocks so formed may not have been regarded as excellent examples of crystal fractionation. What criteria does the theory offer to prevent such a claim from being made in perfect good faith ? Or, to put a broader question, have any criteria been given that would prevent almost any rock of igneous aspect, however formed, from being claimed for this process ?"

In referring to the action of "emanations" Nockolds asks (p. 24) :

" Why should the products of such activity tend towards a plagioclase—potash felspar—quartz cotectic curve which, as we have seen, can be deduced from available experimental data on dry melt systems depending on crystal → melt equilibria ? " Judging from the context this question is related to the development of rheomorphic veins, and the answer is quite straightforward. If the temperature and pressure conditions, etc., are appropriate, fusion of the transformed rock will naturally take place, and the initial melt so formed will represent the most fusible material, i.e. the mixture with the lowest melting range. The case is in no way different from that of the straightforward fusion of rock material, without initial change of composition, the composition of the first formed melt from which Nockolds expects to fall on or close to the plagioclase—potash felspar—quartz cotectic curve. In terms of " colonnes filtrantes ", Nockolds's question was answered thirty-seven years ago by Termier (1910, p. 593).

The actual problem as to why transformed rocks should ultimately attain the composition of granite, whilst still in the solid state, is more difficult. Transformed rocks in general undergo a change that is far too intimately interwoven in the body of the rock to be attributed to introduced fluids, and this suggests that some factor other than crystal → melt equilibria is operative. Indeed it seems most probable that the processes of transformation are dependent on some form of physico-chemical control in the solid state.

In an interesting article on the " logique " of the minerals of granite, de Lapparent (1941) emphasizes the fact that the inter-relations of the minerals in granite cannot be so simply explained as by reference to the consolidation of magma from a condition of pure igneous fusion. Quartz, for example, is commonly the last mineral to crystallize. He correlates the order of crystallization with the part played by Al in the crystal lattices of the minerals of granite. Quartz is built of a continuous mesh of tetrahedral units with O at the apices of the tetrahedra and Si at the centres. The formula of a single isolated tetrahedron so constructed is SiO_4, but in a quartz crystal the tetrahedra are united in such a way that each apex of a tetrahedron also forms the apex of an adjacent tetrahedron. The result is that every O atom is shared by the Si atoms of two adjacent structural units, or, in other words, each Si atom has a half share in each of four O atoms, and the chemical formula corresponding to the lattice structure is SiO_2. De Lapparent points out that the felspars are built up on a similar plan. There is an analogous framework of tetrahedral units, again with O at the apices of the tetrahedra. Here, however, Si occupies the centres of some of the tetrahedra, whereas Al occupies the centres of others. By virtue of the lower valency of Al, as compared with Si, this arrangement makes possible the accommodation of K, Na, or Ca

within the crystal lattice. De Lapparent goes on to point out that the crystal lattices of the micas, amphiboles, and pyroxenes also include the Si–O tetrahedron, and, to a lesser extent than the felspars, the Al–O tetrahedron. He interprets the order of crystallization in granite as dependent on the part played by Al in the crystal lattices of its component minerals, correlating the order with the development of Al–O tetrahedra, a development which starts, increases, attains its maximum development (in the felspars), and ceases; with the cessation of its development Si–O tetrahedra remain as quartz.

During the recent war several petrologists independently reached the conclusion that the transformations that take place in solid rocks, resulting in granitization, are best explained as a result of ionic diffusion. If ionic diffusion is the process concerned, then crystal structure, and not crystal → melt equilibria, will obviously be the main control. Jens Bugge (1946) has recently described the various ways in which ionic migrations take place, and a recent article by Kathleen Lonsdale (1947) is also very instructive in this connection.

Solid diffusion is known to take place in three different ways. (1) Through spaces in the crystal lattice. (2) From one lattice point to another within the crystal mesh. (3) Along the boundaries of closely packed crystal grains. These three methods of diffusion will be discussed in turn.

(1) If the crystal lattice is sufficiently open, and the migrating ions are of appropriate size, then migration may proceed through the spaces in the lattice. Na ions, for example, have in this way been passed through quartz parallel to the *c* crystallographic axis. Any kind of disorder or defect in a crystal lattice increases the possibility of diffusion, and all crystal lattices are defective. For example, crystals are usually not "single", they are composed of minute units termed crystallites. These crystallites may be arranged parallel to each other, but separated by discontinuities, or they may be disorientated by a few minutes or even degrees, although each crystallite may be quite regular in its own internal structure. The possibility of ionic migration will obviously be facilitated along the boundaries of crystallites. The writer referred to this possibility in discussing the replacement of quartz by felspar in the rims of quartzite inclusions within hornblendite in Colonsay. In this example of mineral replacement, the limit of general felspathization within the quartzite xenoliths is sharp. When a large quartz grain lies just at the limit of felspathization it is penetrated by antennae-like outgrowths of felspar which terminate bluntly within the grain. The felspathization follows definite crystallographic directions, the quartz becoming cut up into rhomb-shaped portions (separated by felspar) of roughly similar size which exhibit straight extinction with the diagonals of the rhombs. This suggests that the

felspathization, dependent on introduction of Al and Na or K into quartz, took place most readily along discontinuities in the crystal lattice at the margins of rhomb-shaped crystallites (Reynolds, 1936, p. 383, and fig. 4).

(2) Ionic migrations may also take place by virtue of the fact that a certain number of atom sites (lattice points) in any crystal are unoccupied. In this case the ions diffuse through the crystal by jumping from one lattice position to a neighbouring empty one. This form of diffusion depends on the fact that the atoms in crystals are in a state of rapid thermal vibration about their mean regular positions. These vibrations may be so large that atoms " break loose " and wander through the lattice. This migration is particularly marked in the case of soft metals, so that when two such metals are placed in contact the atoms of one metal may diffuse through the other. Self-diffusion of this type has been traced within Pb by using the radioactive tracer method. When one metal diffuses into another so that an intermetallic compound is formed the boundary of the new phase is perfectly sharp (Desch, 1934), and this fact has an important bearing on the interpretation of sharp contacts that are sometimes exhibited by replacement granites against the country rocks ; sharp contacts may represent diffusion limits. In the replacement of quartz by felspar referred to above, the contact between the felspathized zone and the residual quartzite is remarkably sharp (Reynolds, 1936, pp. 372–4, and pl. xi, fig. 1).

From the petrogenetic aspect, an important point about vibrations in crystals is the fact that the ions of the metallic elements are more loosely bound in the crystal lattice than the anions. Thus the ions of the metals will migrate through the Si–O or other framework.

(3) Ionic migrations will obviously take place with the greatest ease along the crystal boundaries of closely packed grains. This accounts for the fact that felspathization of quartzite commonly proceeds around the margin of grains, so that the rock acquires the appearance of quartz grains embedded in a felspathic cement. With a greater development of felspar at the expense of quartz the residual quartz grains may finally remain as rounded poikilitic inclusions in felspar crystals (Reynolds, 1936, p. 383).

As already stated, disorder and defects in the crystal lattices, which are always present, increase the possibility of diffusion ; moreover the presence of a foreign atom in the lattice increases the ease of migration, so that once the process of ionic migration from one crystal to another has started it will tend to facilitate further migration. Rate of diffusion increases with rise of temperature, and reactions between solids are usually exothermic, so that they will usually be accelerated autocatalytically.

From the above discussion it will be clear that if migratory Al ions become fixed within the crystal lattice of quartz, on the sites of Si atoms, the valencies would then be such that migratory Na diffusing through the crystal mesh could become fixed, and slight distortion of the initial quartz lattice would convert it to that of felspar. Such a change, however, is dependent on an initial introduction of Al into the quartz lattice (cf. de Lapparent's " play of Al "). If processes of ionic diffusion are operative in the genesis of granite from pre-existing rocks it should obviously be possible to find examples of quartz which contains small amounts of Al. Small quantities of impurities can only be detected by spectrographic analysis, and it is of the utmost importance to find that in nineteen spectrographic analyses (Bray, 1942) of quartz from Pre-Cambrian granites and pegmatites, Al was found to be present in every case. Of these analyses twelve were quantitative and Al_2O_3 was found to form as much as ·77 per cent of one example, ·70 of another, and to average ·31 per cent. Other constituents found to be present in the analysed samples of quartz are Fe, Mg, Ca, Ba, and Ti.

" Emanations " are no longer of entirely unknown origin, and only to a very small degree do they come from unknown depth. They have been traced to chemical interchanges—explicable by known physical processes—between adjacent rocks. As Backlund has more than once pointed out, all that is required to start the " chain reaction " is an initial small introduction of Na and Si into pelitic rocks. As geosynclinal sediments, with their intercalated basaltic rocks, become granitized, constituents including Fe, Mg, and Ca are displaced. The destiny of these cafemic constituents is no longer a riddle : they are fixed in the basic fronts of granitization (for references see Reynolds, 1946, 1947) where they have given rise, according to the geological milieu, to regional zones of basification—the zones of regional metamorphism, to the amphibolitization of limestone and basaltic rocks, to biotite and cordierite enrichment in contact aureoles, and to the basic, so-called igneous, roof-rocks of post-tectonic plutonic complexes. Granitization and the complementary basification are major petrogenetic processes adequate to account for associations which suggest the term " contrasted differentiation " (Nockolds, 1934).

Magmatists, adopting a defeatist attitude, have begun to conceive of petrology as a restricted branch of physical chemistry. Transformists, on the other hand, are striving to establish petrology as an integral part of geology, in the firm belief that the so-called igneous rocks cannot be interpreted, nor the history of our planet be completely told, until due attention has been paid, not only to the more obvious field appearances presented by plutonic rocks themselves, but also to their complete geological setting in both time and space.

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A Seismic Investigation on the Outflow of Windermere

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Introduction

ONE of the most prominent features of an ice-eroded region is the formation of a number of basins scoured out of the bed-rock by the ice and rock frozen into it. When the ice has retreated these basins usually fill up with water, thus forming lakes, and Windermere appears to occupy two small basins scoured out of the floor of a valley which extends to the south as far as Cark, where it joins the coastal plain. It is, therefore, difficult to explain why the natural outflow of the lake should be through the Leven valley, a gorge extending from Newby Bridge to Haverthwaite, instead of through this broad valley which must have existed when the lake was formed (see map).

There are several possible explanations which may be put forward. One is that the outflow was once through the Cartmel valley, but that this stream was captured at the foot of the lake by another stream in the Leven valley eroding back its head. Another explanation seems to be that the end of the glacier which lay in the Cartmel valley separated from the main body, leaving stagnant ice in the lower extremities. The water flowing from the foot of the lake, or glacier, was then prevented from flowing down the valley and found some other escape over a low col or along an already existing line of weakness into the Leven valley. A third explanation suggests that the stream flowing from the foot of the glacier was deflected by glacial deposits jettisoned during the retreat. Finally it may be that the glacier, whilst flowing freely through the Cartmel valley, overflowed a col into a side valley already in existence and eroded a course whose bed finally lay at a lower level than the floor of the main valley. An objection that may be offered to this suggestion is that the Leven valley does not show the characteristic U-shaped section, but this, though usual, does not appear to be necessary. The Naerodal trough in Norway has not a U-shaped form, but tends towards a V section, though it is certain that ice has flowed through it.

It was to test the merits of these hypotheses that a series of experiments was carried out, the principle being to find the thickness of glacial, and other, deposits above the Palaeozoic bedrock at intervals along the Cartmel valley, and thus be able to say whether there was ever a possible outlet for Windermere, in its present state, through the valley. The problem is suitable for solution by refraction seismic methods as the velocity through the bedrock is over three times as

great as that through the overlying deposits. In addition an experiment was performed near Backbarrow in the Leven valley, to estimate the thickness of deposits near the existing outflow.

Technique

The experiments comprised exploding a small charge of gelignite in the ground and recording the oscillations on six geophones placed in line with the charge. The electrical output from each geophone was amplified and applied to a moving coil galvanometer. Teledeltos recording was employed in these experiments. The principle is to apply a voltage to a stylus, attached to a moving coil galvanometer which causes a current to flow through the light grey recording paper. The paper decomposes under the action of the current and a black compound forms where the stylus has passed over the paper, thus giving a permanent record of the movement of the galvanometer. It has the additional merit that all the styluses can be watched just prior to the explosion, and should there be any source of disturbance, such as a passing motor car, transmitting oscillations to the ground which tend to mask the arrival of the explosion wave the experiment can be delayed until the disturbance has died away. A separate stylus was used to record the instant of explosion, and dots were marked on the recording paper at equal known intervals to time. Any sharp deflection of the galvanometer pen could be read to an accuracy of 1 milli-second. A graph of the time of the first arrival at each geophone against the distance of that geophone from the shot point was plotted. The plotted points were found to fit one or two straight lines, the slopes of which give the velocities of sound through the upper and lower layers whilst the depth of the interface can be derived from the intersection of the two lines.

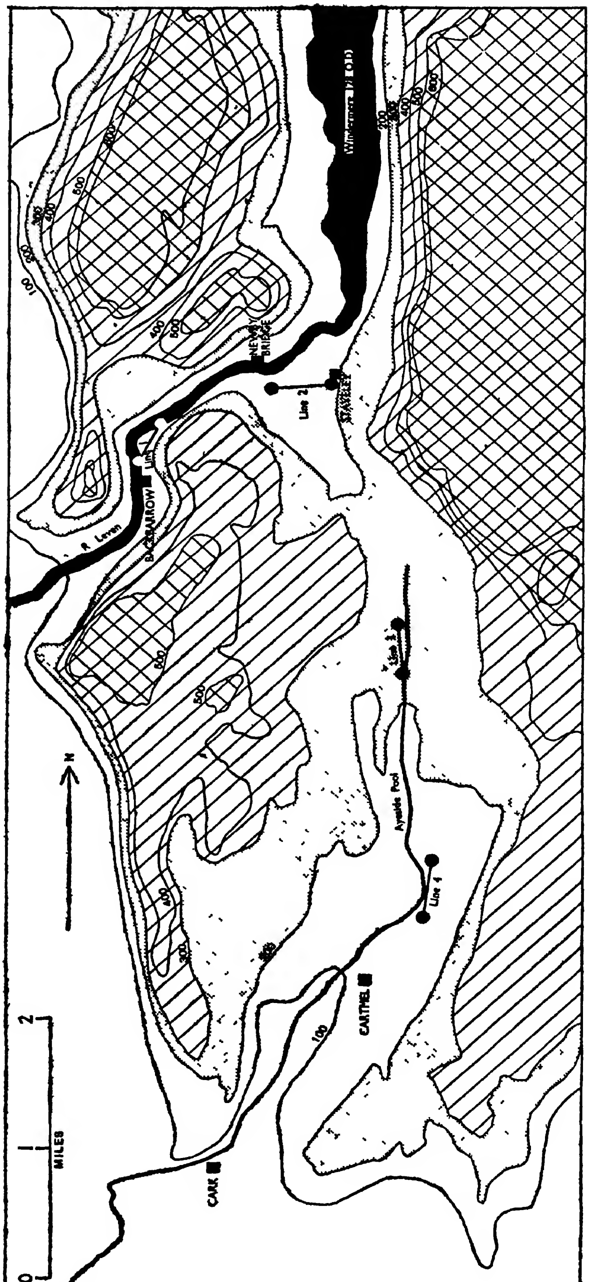
The method of least squares was employed to calculate the best straight line through the points of the graph and the theory of errors to find the standard deviation from the best straight line. Bullard (1940) [1] gives a full description of seismic procedure and the reduction of results in a paper on the Palaeozoic Floor of Eastern England.

Results

The first 1,000-ft. line was shot across an arc of the River Leven where it runs through the gorge at Backbarrow, and the resultant time-distance plot of the first arrivals at the geophones was a straight line having the equation :—

$$t = (0{\cdot}010 \pm 0{\cdot}003) \text{ sec} + D/(16{,}300 \pm 1{,}300) \text{ ft./sec.}$$

[1] Bullard, E. C., Gaskell, T. F., Harland, W. B., and Kerr Grant, C., 1940. Seismic Investigations on the Palaeozoic Floor of East England. *Phil. Trans.*, A, 239, 29–94.



TEXT-FIG. 1.—Map showing position of seismic lines in relation to relevant topography.

where t sec. is the time of the first arrival at a distance D ft. from the shot point.

This implies that the first arrivals have all travelled through the Palaeozoic bedrock. The intercept of $(0 \cdot 010 \pm 0 \cdot 003)$ [1] sec. is due to the presence of a surface layer having a velocity assumed to be (4,000 ± 1,000) ft./sec., which gives the thickness of these recent sediments as (22 ± 8) ft., to which 2 ft. must be added as the charge was buried 4 ft. from the surface. This gives the expected result that there is no great thickness of drift in this part of the cross section of the valley. The thickness (22 ± 8) ft. may comprise not only sediments but also a low velocity weathered layer on top of the Palaeozoic floor.

A second line of 1,500 ft. was shot across the Cartmel valley about a half-mile south of the lake-foot. The line was so placed that its two extremities were within 50 ft. of the rock outcropping on either side of the valley. Here again the plot of first arrivals was a straight line which could be represented by the equation :—

$$t = (0 \cdot 012 \pm 0 \cdot 002) \text{ sec.} + D/(14{,}300 \pm 500) \text{ ft./sec.}$$

Assuming the glacial sediments overlying the Palaeozoic to have a velocity (4,000 ± 1,000) ft./sec., the thickness of this layer is (25 ± 7) ft. Correlation with Ordnance Datum levels makes bedrock (9 ± 7) ft. beneath the present lake level. The linear nature of this graph and the small value of the standard error in the velocity determination show that the bedrock floor of the valley was even and not appreciably curved.

The third line was measured out at Ayeside Pool in a direction parallel to the axis of the valley and at the lowest point of the cross-section. The line was shot along the valley because it would then be refracted at a flat or gently inclined interface which makes the resulting time-distance curve a straight line, and as it was shot in both directions this enables not only an accurate determination of the depth to be made, but also any significant inclination of the valley floor may be found. It was not considered that there would be any great error due to a slight displacement of the seismic line from the axis of the bedrock, as the valley had the characteristic glaciated U-shaped form which implies that the floor is appreciably flat. It would not, however, detect a deep channel through the bedrock unless this channel happened to pass under the seismic line.

When the line was shot from its southern end it was found that the resulting plot could be represented by two straight lines. From 0–110 ft. the relation is :—

$$t = (0 \cdot 002 \pm 0 \cdot 002) \text{ sec.} + D/(6{,}100 \pm 1{,}100) \text{ ft./sec.,}$$

[1] The value ± ·003 sec. is the standard error of intercept derived from the theory of errors.

and from 150 ft. onwards :—

$$t = (0{\cdot}014 \pm 0{\cdot}002)\text{ sec.} + D/(19{,}300 \pm 1{,}700)\text{ ft./sec.}$$

This indicates a total depth to bedrock of (44 ± 9) ft. at the shot point. This line was also shot in the reverse direction (i.e. from the northern end) giving a line of equation :—

$$t = (0{\cdot}009 \pm 0{\cdot}003)\text{ sec.} + D/(17{,}100 \pm 800)\text{ ft./sec.,}$$

which implies that this shot was fired down the dip of the glacial sediment—Palaeozoic floor interface, to the geophones, but that the slope of the interface is small (1·2 degrees).

The depth of drift, (44 ± 9) ft., makes the bedrock (52 ± 9) ft. above the present level of the lake.

A fourth line was measured out at Aynesome, near Cartmel. This again was parallel to the axis of the valley and at its lowest point. The graph gave two straight lines with equations :—

$$t = (0{\cdot}005 \pm 0{\cdot}002)\text{ sec.} + D/(4{,}200 \pm 100)\text{ ft./sec.,}$$

$$\text{and } t = (0{\cdot}027 \pm 0{\cdot}001)\text{ sec.} + D/(16{,}600 \pm 800)\text{ ft./sec.}$$

Assuming that the intercept of the first line is due to a weathered layer which has a velocity less than 2,800 ft./sec. the maximum total thickness of recent sediments is found to be (54 ± 3) ft., which makes the bedrock (37 ± 3) ft. below the level of the lake.

Conclusions

The observations show that neither in the Leven or Cartmel valleys is a great thickness of glacial sediment to be found and that Windermere at its present level could not have flowed out through the Cartmel valley, as the bedrock at Ayeside is (52 ± 9) ft. above the present water level. At Newby Bridge there is a sill that would render Windermere stagnant at any lower level, but at anything less than 50 ft. above its present level the only outlet is through the Leven valley. An examination of the sediments round Windermere has shown some evidence for a raising of water level, but this is much less than 50 ft. This means that when the ice retreated after the last stage of the ice age, the sill in the Leven valley must already have been substantially lower than the rock bar in the Cartmel valley. Therefore the outflow through the Cartmel valley has never been blocked in the true sense of the word, but somehow an outlet at a lower level formed during the ice age. It would be interesting to find out whether this outlet is water or ice eroded.

Major Clues in the Tectonic History of the Malverns

By N. L. FALCON [1]

GENERAL

DURING recent work for the D'Arcy Exploration Co. the writer found it necessary to attempt to understand the structural history of the Malvern Range. The widespread conception of violent "Armorican" earth movements, almost simultaneously acting in directions at right angles to each other in a relatively small area, did not appear satisfactory. No important tectonic contribution to Malvern literature has appeared since Groom's work published in 1899 and 1900, conveniently summarized in *Geology in the Field* in 1910. Text books either ignore the problems completely and generalize strangely,[2] or say practically nothing about them.[3] To separate fact from later theory it was necessary to go back to the original surveys. As a result the writer finds himself unable to accept Groom's conclusion on the age of the movements causing the overturning, and in places imbrication, of the Silurian and Lower Old Red Sandstone rocks on the west side of the range. He is also strongly of the opinion that the evidence for the great Malvern Fault, separating the Trias from the older rocks on the east side of the range, has been much overplayed.

Nobody is likely to be able to compete with Murchison, Phillips, and Groom on field evidence, and it is most improbable that any critical exposures have been missed. Even with a very limited knowledge of the ground, however, it is legitimate to draw one's own conclusions from the recorded evidence in the light of more modern trends of thought. This note gives the writer's reactions to the recorded evidence. It will be in two parts, one dealing with the date of the overturning and associated thrusting, and the other with what has become known as the "great Malvern Fault".

[1] This note is published by permission of the Chairman and Directors of the Anglo-Iranian Oil Co., Ltd.

[2] In *Handbook of Geology of Great Britain* (Evans and Stubblefield), Dr. Morley Davies writes on p. 2: "The Malvernian System of north and south direction includes more faults than folds. It is of post Carboniferous and partly of Triassic age . . . The main feature of this system is the great Malvern Fault which for many miles separates the Archaean and Palaeozoic rocks on the west from the Trias on the east."

[3] Dr. E. M. Anderson, for example, in *The Dynamics of Faulting*, omits reference to the Malverns when discussing Armorican stress systems, although, on p. 105, he excludes the Malverns from the Caledonian stress system. An exception is Dr. L. J. Wills, who, in his ***Physiographical Evolution of Britain***, includes a short paragraph on p. 340 which appears to be in general agreement with conclusions (1) and (2) of this paper.

A. The Date of the Overturning

While Groom's mapping added a great deal of detail to the Malvern picture, it left the general tectonic picture on the west side of the range very much as it had been left by Phillips, and as it is still to be seen on the one-inch to the mile Geological Survey Sheets of to-day. The only important change introduced by Groom, which vitally affects the history of the area, is the westward overturning of the extremely badly exposed Coal Measures (now accepted as Upper Coal Measures) in the southern tongue of the Forest of Wyre coalfield, on the west side of Woodbury Hill. Groom's section incorporating this overturning (see 1900 paper, fig. 27) has received great publicity, and has almost become a dominating " fact " in some text-books and summaries.[1] It is as well, therefore, to examine its basis.

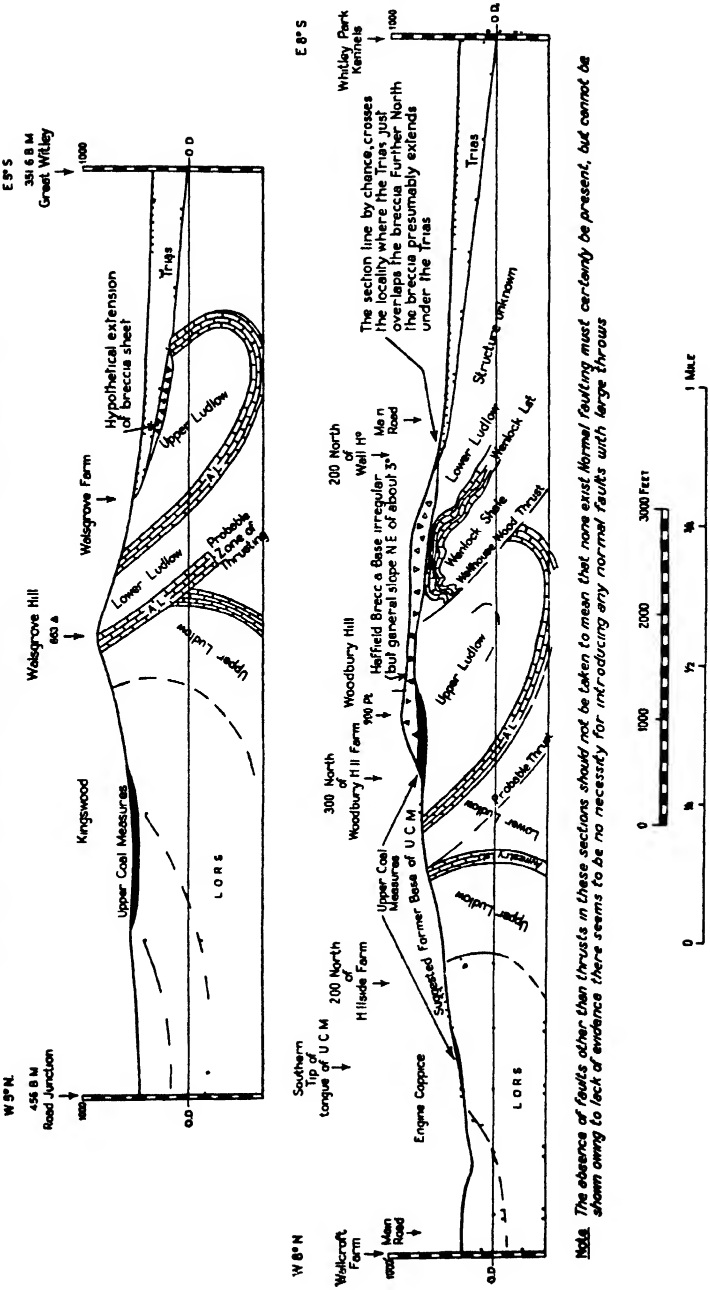
In his 1900 paper, Groom states clearly that he made a special examination of the northern, or Abberley Hills area, with the object of determining whether any portion of the Coal Measures shared in the over-folding of the Silurian. It appears that his interest led to the clutching of a straw. Groom's map (fig. 15*a*) shows five dips in the tongue of Coal Measures. Three of these are at the centre of the tongue on the west side, where horizontal Coal Measures were seen resting on horizontal Old Red, another is a dip of 35° on the south-east side of the south end of the tongue, shown on his map directed N.N.E., but referred to in his text (p. 175) as N.N.W. It is the fifth dip which Groom has accepted as overturned ; he was also influenced by the shape of the tongue.

Of this fifth dip he writes : " An important section in a hopfield west of Ridge House shows soft ferruginous sandstones and clays, with bits of coal—undoubtedly belonging to the Coal Measures—dipping 30° E.S.E." His map shows this dip 50 feet west of the Old Red Sandstone outcrop at the foot of a slope rising towards Woodbury Hill at an angle of about 20°. He also writes : " Still further north, close to the inverted grey sandstone, greatly contorted clay, overlain and underlain by clearly stratified shaly coal, may be seen on the bank of the stream. These beds are thrown into a small dome, about 5 feet across, overfolded towards the east."

Without referring to the lines of section on the map, it is possible to overlook that Groom's section is drawn at 45° to the strike and topographical slope, thus exaggerating the degree of overturning (if the dips have been adjusted to the oblique direction), and increasing the width of the coal measure outcrop. It is clear that the section is a

[1] The section is reproduced in *Geology in the Field* (Geol. Ass., 1910, p. 723, fig. 121) ; Jukes-Browne, *Building of the British Isles*, 1911, fig. 25 ; Evans and Stubblefield, *Handbook of Geology of Great Britain*, 1929, fig. 17 ; *British Regional Geology* (" The Welsh Borderland "), H.M. Geol. Survey, 1935, p. 72.

SECTIONS ACROSS THE ABBERLEY HILLS (NORTH END OF MALVERN LINE) TO SHOW PRESENT STATE OF KNOWLEDGE OF TECTONIC HISTORY



Note The absence of faults other than thrusts in these sections should not be taken to mean that none exist Normal faulting must certainly be present, but cannot be shown owing to lack of evidence there seems to be no necessity for introducing any normal faults with large throws

diagrammatic picture only, and ignores the possibility of creep affecting superficial dips. The writer has recently seen in Woodbury Quarry (1,000 feet S.S.W. of Woodbury Old Farm, called Woodbury Farm Reformatory on Groom's map), a clear case where creep from the hill has affected the Ludlow beds on a similar slope, and increased the overturning of a true dip of 85° E. to a false dip of 40° E., the false dip extending 10 feet below ground level. It is thought that if this has happened to well-bedded Ludlow rocks, an exposure in a hopfield of soft sandstone and clay, which is unlikely to have been deep, will also probably have been affected by creep, and that it is therefore most unwise to give it regional significance. The other exposure mentioned with overturning *towards* the east, in contorted clay, is strongly suggestive of superficial disturbance, and it is interesting to note that Groom has ignored it. It is clear, therefore, that the tectonic overturning of the Coal Measures is based on very flimsy evidence ; the writer feels unable to accept it.

Murchison's very clear sections (plate 36, fig. 1, 2, and 3) show that he found no evidence for overturning of the Coal Measures, but regarded them as resting, with gentle dips, unconformably on the older rocks. The small strips of Coal Measures mapped by Murchison and Phillips on the hill, were not actually seen by Groom. Murchison wrote (p. 135) : " The Coal which was extracted on the western slopes of Woodbury Hill, and south of the Hundred House, consisted merely of thin shreds of carbonaceous strata, thrown up in elevated positions or rather squeezed up in separate patches between the trap [1] and Silurian rocks. These poor and shallow deposits were necessarily soon exhausted, and no accurate record of the works remain." Fortunately Murchison left one incontrovertible record. On p. 421 he gives a sketch of a patch of Coal Measures resting with almost horizontal dip on Silurian rocks exposed in a quarry, cut in Walsgrove Hill, and states : " Grits of the coal measures adhere in broken patches to the side of the elevated mass, and small troughs of coal have been worked out in the depressions on the eastern side of the ridge."

It seems evident that the Upper Coal Measures are as violently unconformable and as gently dipping in the Walsgrove and Woodbury area as they are at Newent and in the Forest of Wyre and elsewhere.

It appears, therefore, that the only real evidence for folding movements between the Upper Coal Measures and the New Red rocks in the Malverns is the difference of dip between the Upper Coal Measures and the Haffield Breccia.[2] This does not require intense movement along a localized zone to explain it.

[1] Now Haffield Breccia.

[2] The age of the Haffield Breccia is post-Upper Coal Measures/pre-Trias. It may be regarded most conveniently as a foreland product of the Variscan orogenesis, being formed by the erosion of local Archaean masses.

The two sections accompanying this note, which are offered as a substitute for Groom's section, summarize the present state of knowledge in the Woodbury Hill and Walsgrove Hill area, as visualized by the writer. They have been drawn from the 6 in. O.S. topographical map, using Groom's geological map and diagrams and Murchison's sections, and are true to scale horizontally and vertically.

The Evidence Available for Dating the Overturning

The westerly overturning has affected rocks up to Lower Old Red Sandstone age, and there is no sound basis (see above) for assuming that it has affected the Upper Coal Measures. It must have occurred therefore, some time during the interval. There are only two lines of approach for attempting to narrow these limits, one by studying the evidence of angular unconformities in surrounding areas, and the other by the discussion of trends. The first is undoubtedly the most important, for while folding involving overturning must produce, at any rate locally, marked angular discordance at the base of strata subsequently deposited, trends are variable, and we can have no precise knowledge of their meaning.

As is well known, angular unconformities between the time limits under discussion occur between the Lower and Upper Old Red Sandstone, at the base of the Carboniferous Limestone, and between the Middle and Upper Coal Measures. In the area surrounding the Malverns there is no marked angular discordance preserved between the Lower and Upper Old Red Sandstone. The choice, therefore, appears to lie between the pre-Carboniferous Limestone and pre-Upper Coal Measure upheavals. Unfortunately as the evidence is inconclusive, the choice becomes a matter of opinion. The writer, after making allowances for the lack of data on the pre-Carboniferous Limestone unconformity, is more impressed with the pre-Upper Coal Measure unconformity in the Malvern area.

The Middle Coal Measure outliers on the Clee Hills (and, in the writer's opinion, the presence of bituminous residues in Ordovician and older rocks in the Shelve area) indicate that the Middle Coal Measures once extended much further south over St. George's Land. One has therefore a definite need for postulating a great cycle of uplift and depression in this area between Middle and Upper Coal Measure times. Although there is only negative evidence to indicate that movement of similar intensity has not occurred in the area at the other two periods in question, it is a natural preference to attribute the Malvern overturning to the nearest evidence of violence. Further north, in the West Pennine area, there is evidence of asymmetric folding, to the west, affecting Middle Coal Measures, but apparently no evidence that later sediments have been sharply folded.

Theoretical discussion of Trends

The apparently anomalous north–south trend of the Malverns has long attracted attention, the anomaly being due to the practice of attributing both movements to the post-Upper Coal Measure, pre-Permian, time interval. In the whole Welsh Border area, however, trends are very variable in the Silurian, Old Red Sandstone, and Carboniferous rocks, and it is not easy to decide on any standard. Thus while the Malvern folding and overturning and the Usk anticline run north–south, the Woolhope anticline is N.W.–S.E., the Ludlow anticline E.N.E.–W.S.W., and the west margin of the Bristol coalfield folding N.E.–S.W. ; even the Malvern Line turns locally N.E.–S.W. in the Abberley Hills.

A conception which removes the necessity for visualizing strong independent forces from the east [1] to account for the Malvernoid overturning is to regard the varying strikes of the folds between the Church Stretton zone and the Trias to the east as the result of late Caledonoid movements, culminating at the end of Middle Coal Measure times. We have then to visualize a relative force from the north-west opposed by the rigidity of a basement with a N.W.–S.E. strike (Charnoid of St. George's Land). It would appear inevitable that such a stress system would produce a tendency towards thrusting or tear faulting along N.–S. lines, particularly where the basement trends meet. It appears that the Malvern line fits this conception very well, particularly the great increase in the degree of overturning from south to north until, in the Abberley Hills, there is a zone of imbrics incorporating at least one basement slice, and at Abberley itself the strike of the sheared Silurian is slewed round N.E.–S.W. Another difficulty which disappears under this conception is the Caledonoid strike on the north-west side of the Bristol Coalfield ; available evidence does not conflict with the suggestion that this strike was impressed on the area in pre-Upper Coal Measure times.

If, however, the existence of a separate westerly movement is preferred, there seems no reason why these wide variations of trend should not be attributed to the interaction of a relative movement to the West, on a basement previously moulded on N.W.–S.E. or N.E.–S.W. lines, to which directions all previous movements known to have violently affected the area conform (pre-U. Llandovery and pre-Cambrian).[2] The limited real evidence does not conflict with the

[1] In *A History of British Earthquakes* (p. 17), C. Davison states that of the four systems, Caledonian, Charnian, Armorican, and Malvernian, earthquake records show that present activity is by far the most impressive in the Caledonian direction, and that the Malvernian direction is most rarely apparent.

[2] There is no real evidence that pre-Devonian Caledonian movements produced any folds with a N.E.–S.W. strike in the Welsh Border area east

suggestion that all the axes, affecting rocks varying in age from Upper Llandovery to Middle Coal Measures, may have been produced by a westerly movement exerted intermittently throughout a long period and culminating at the end of Middle Coal Measure times. This alternative is less attractive to the writer than that given in the last paragraph, but it is a less difficult conception than that of vague late Caledonian movements, followed by equally vague inter-Carboniferous movements, culminating at the end of the Carboniferous period with violent forces acting at right angles to each other.

B. The Evidence for Post Triassic Faulting on the East Side of the Malverns

Perhaps because Geological Survey maps and Groom's map show a great fault line running down the east side of the Malverns, it has become the practice to assume that this is a proved phenomenon. It is well, therefore, to examine the facts involved.

Murchison considered that the New Red rocks were unconformable against the east side of the Malverns, and that the upper members of the New Red overstepped the basal members. Phillips (see the section on p. 7 of his *Memoir*) held a like view, with the addition that the old Triassic shore line was the product of a pre-Triassic fault. Hull regarded the Malvern and Abberley Hills as a shore line against which the Trias overlapped. The original survey map of Phillips in his *Memoir* showed no fault, but when the old series Survey 1 in. map (Sheets 55 N.E. and S.E. ; 43 N.E. and S.E.) was published in 1855, with the addition of the names Aveline, Howell, Williams, Selwyn, and Ramsay, all the post Triassic faults had appeared on it, and have remained thereafter.

Groom in his 1900 paper, went carefully into the evidence. His conclusion was that there is a fault, but not so large as often thought. By the somewhat speculative process of assuming that Triassic and Permian thicknesses are known, he estimated that the throw varied from less than 200 feet at the southern end of the Malverns to about 1,000 feet at Woodbury Hill. His diagram (fig. 30) shows that he accepted an overstepping of the Keuper on the Upper Bunter Sandstone, and also an overlapping of the Bunter Pebble Beds and Haffield Breccia by the Upper Bunter Sandstone. It is clear, therefore, that Groom actually thought the faulting was subsidiary to the overlapping and overstepping.

Groom's treatment of the evidence seems very reasonable, but, with other writers, he accepts the presence of a fault breccia as a fact,

of the Longmynd ; the " Caledonian " strike of the pre-Cambrian rocks of the Longmynd itself is probably largely a pre-Cambrian feature.

and it is necessary to inquire into the basis for this. I have, however, been able to find nothing in the literature to prove that the known breccias are not erosion breccias, indeed recorded observations appear to be in favour of that alternative interpretation.

The " fault breccia " has only been definitely seen at three points, in the Malvern tunnel, on the east side of Midsummer Hill, and at Malvern Link Quarry. Holl, who accepted the idea of a large fault, wrote " along the eastern foot of the Malverns this fault is indicated by a line of brecciated rock made up of fragments from the adjacent hills, which, within the entrance to the tunnel was ascertained by the Rev. Mr. Symonds to be about 9 yards in width ". This is, however, an exaggerated uncritical account, because not only does it accept the breccia as a fault breccia without examination, but it conflicts with the facts. As Groom wrote (1900), " The actual junction of the rocks on the two sides of the boundary has rarely been seen," and the Rev. Mr. Symonds (see below) actually described the breccia as an erosion breccia.

Groom mapped the fault, as did the Survey Officers, by following a change of topographical slope, which can be due either to faulting or unconformity. Groom writes (p. 192) that " a remarkable feature of this fault is the curious way in which it tends to follow a line parallel to the western [1] margin of the old mountain chain ; it repeats in a striking way the sinuosities of the latter ". Such contouring is more usual with unconformable overlap than normal faulting, and was one of the reasons why Murchison, and Phillips, mapped the junction as an unconformity.

The breccia has not been described often, but the few descriptions available are of the utmost importance. Murchison (p. 52) refers to the basal red sandstones and conglomerates visible in one or two spots at and near Great Malvern, on the west side of the Ledbury–Tewkesbury road " adhering to the steep slopes of the syenite ". He also refers to a farmyard north of Foley Arms excavated in the surrounding rock, which " on one side of the yard is a soft deep red sandstone, with a thin band or two of fine conglomerate (fragments in size from walnuts to peas) the beds dipping 35° E.S.E." and says that the foundations of many of the houses along the lower terraces of Great Malvern are excavated " in deep red sandstone which overlies the fine conglomerates ". Phillips (p. 140) writes : " The eastern face of the Malvern Chain is on a fault line sloping about 60°," but his section, referred to above, suggests that he was referring to a pre-Triassic fault. Groom (1900, p. 192), states that at Midsummer Hill and Malvern Link the breccia " consists of angular fragments of Archaean and Triassic rocks ". He also states that : " At

[1] He does not mean Eastern !

Malvern Link the faulted surface of the Archaean, with its covering of breccia, is admirably shown," but somewhat inconsequentially continues : " The fault here displays its characteristic sinuous course and dips N.E. at 65° to 75°, usually between 65° and 70°. It is therefore a normal fault." It is evident that we must go to the railway tunnel for definite facts on the breccia problem.

When the tunnel was first made it was examined by the Rev. W. S. Symonds and A. Lambert. These authors (the article appears actually to have been written by Symonds) state : " The Lower Keuper Marls dip away from a syenitic and brecciated rock, against which they rest conformably at an angle of 50°," and " I was puzzled, at first, whether or not to rank the brecciated syenite as an equivalent of the Haffield Permian breccia, as there is evidence of stratification. The stratification, however, is but partial, and I am inclined to look upon the brecciated rock as a portion of an ancient beach or talus derived from the syenitic ridge ". The relevant part of the explanation of the geological section through the tunnel (fig. 1 of the paper) reports, from the tunnel mouth to the syenitic breccia, a distance of 154 yards : " Keuper marls and sandstone, twisted and broken ; sometimes nearly horizontal, and sometimes with a dip of 50°."

When the railway tunnel was doubled in 1925, the works were examined by T. Robertson of H.M. Survey. This observer writes of the Keuper marl at the tunnel mouth, " the green bands reveal the structure as a gentle anticline, broken in three places by small faults with throws varying from 5 to 15 feet, the downthrow in each case being towards the hill, i.e. westward." A clear photograph is given of this section. Continuing the description through the tunnel, " the beds flatten and a synclinal axis is crossed at 40 feet inward. Near here, and indeed throughout the Keuper zone in the tunnel, there are numerous slips of at most a few feet in throw, all of them throwing down towards the Archaean. The bedding is shown chiefly by the greenish bands. Beyond the synclinal axis the beds rise, attaining a maximum eastward dip of about 45° at 170 feet, after which they flatten again westward towards an anticlinal axis at about 450 feet. Beyond this there is a fault at 475 feet, throwing down the beds about 8 feet westward. For the next 20 feet the dip is westward at a low angle, and then at 495 feet the marls rise sharply at 45° along the face of the Archaean boundary-fault." No increase of arenaceous material downward was reported. The boundary fault is accepted without discussion.

Lack of critical discussion also characterizes the paragraph describing the Keuper and Archaean Junction which extends from 505 feet to 525 feet from the tunnel mouth. As this is the most important evidence available, it is quoted complete. " On the Keuper side it is a clean-cut

fault, coursing northward at an angle of 80° to the line of the tunnel [1] and dipping eastward at 45°. At 495 feet the Keuper beds suddenly tilt up parallel to the faultplane, but are not broken till within a foot of the fault. Then follow 20 feet of breccia, composed of Archaean fragments, up to about 3 inches in diameter, embedded in a marly matrix. No other rock was seen. The breccia is uncemented, in contrast with that to be seen in the quarries at North Malvern, where it forms a hard cake adhering to the unbrecciated Archaean. The breccia in the tunnel passes gradually westward into somewhat less disturbed Archaean, but the rock is much broken for a considerable distance. The surface evidence is confirmatory. The approximate position of the fault can be located with ease from the topography, and shows that the general dip of the faultplane is not much steeper than that of the section shown in the tunnel, namely 45° to 50°. On the hill the exposures of Archaean near the fault are also invariably broken in this portion of the range."

The contrast between the 20 feet of brecciated Archaean, and the one foot of broken Keuper, is difficult to explain tectonically.

It is interesting to note that the Archaean and Upper Llandovery junction in the tunnel on the west side of the range showed the Archaean was not appreciably broken, even within a few feet of the contact. Here there can be no disagreement with the evidence for moderate overthrusting between the Archaean and unconformable Silurian, which suggests that the disturbed Archaean on the east side of the range may be a superficial phenomenon. Robertson (pp. 163, 165), refers to many slip-planes faced with green or red clay between 540 and 750 feet from the tunnel mouth, and to iron staining from 540 to 750 feet. He also states that : " At 810 feet a cavity lined with barytes appears still to indicate connection with the Triassic rocks on the east, but west of this no trace of the influence can be seen."

At Knightwick, where the Trias can be seen to be faulted against the Silurian in a railway cutting, the occurrence is considered by Groom and the Survey Officers to be a local phenomenon west of the supposed main boundary fault. At Blaisdon, on the south-east side of the May Hill inlier, another place where surface evidence is available to support faulting between the Trias and Silurian, the fault line is on the line of, but not a direct continuation of, the main boundary fault, which is omitted entirely on the Survey map in the Newent area. On the 1 in. geological survey map, north of Woodbury Hill, a fault between the Trias and the older rocks has been shown apparently stopping abruptly at, or passing under, the Upper Coal Measures. This reflects on its veracity.

None of the comparatively few deep borings in the Trias near the

[1] The tunnel direction is N. 60° E–S. 60° W.

Malverns requires the assumption of a steep pre-New Red surface to explain its record. As the original slope was probably smaller than it now is by the amount of post-Triassic tilting, the relative scarcity of scree material as compared with the Mendips (used as an argument for faulting by some authors) may be due to a softer topography, and the absence of limestone debris which is known to have a marked propensity for recementation in desert climates. It will be recalled that in Charnwood Forest the unconformable Keuper rests on pre-Cambrian without important basal breccias. The soft red very false bedded Bunter sandstones, where they can be seen along the foot of the Malverns, look like dune material.

C. Davison has correlated the only recorded earthquake on the Malvern line (1907), with minor slippage along the "great fault which skirts the east side of the Malvern Hills". His reasons are that the seismic evidence suggests a mean direction for the fault of N. 6° E., a hade to the east, and an isocentre $1\frac{1}{2}$ miles east of Great Malvern Station. It would, however, have been equally justifiable to have taken N. 25° W. as the trend of the great fault line at Malvern, and, as suggested above, the easterly hade of the fault is not a proved phenomenon. Moreover, even slight slippage would probably have produced some effect in the tunnel, and of this there is no mention.

The isoseismal lines, as shown by Davison, are very nearly circular, and a very slight adjustment to the map would make the long axis parallel to the Caledonian or Charnian strike, instead of very approximately N.–S., as Davidson shows it. It seems that the most we can deduce from this minor earthquake is a slight slip in or under the Trias $1\frac{1}{2}$ miles east of the supposed great boundary fault, with a strike somewhere between N.E.–S.W. and N.W.–S.E.

It is suggested, therefore, that until further evidence comes to light, it is reasonable to consider the eastern side of the Malverns as marked by a Triassic unconformity, modified locally by minor post-Triassic down-faulting. The question of pre-Triassic faulting must remain open, although it is of considerable importance in speculative inquiries about the Palaeozoic floor under the Mesozoic rocks further east.

Conclusions

(1) The overfolding and overthrusting of the Silurian and the overfolding of the Lower Old Red Sandstone on the west side of the Malverns occurred during the interval between the end of the deposition of the Lower Old Red Sandstone and the beginning of the deposition of the Upper Coal Measures.

(2) From a study of the limited regional evidence it is probable that the overturning took place during the violent movements which preceded the deposition of the Upper Coal Measures.

(3) Available facts tend to show that, pending further evidence, the east side of the Malverns must be regarded as a Triassic unconformity, akin to that so well exposed in Charnwood Forest, and not to a major post-Triassic fault.

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The Origin of the Amphibole-Schist Series of Pahang, Malaya

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1. LOCATION OF THE AREA

THE Amphibole-Schist Series appears to be confined to Malaya east of the Main Range, and it is most abundantly developed in north-west Pahang. It occurs partly in the Main Range Foothills, partly between them and the Main Range granite in the Sua-Kerla-Kelubi-Tempoi river system of the Telom Valley, in the Jelai Kechil valley, in the Sungei Lipis and in the Chembatu-Batu-Cheroh system between Batu Malim and Cheroh, Raub District. So far as is known these crystalline schists do not extend far northwards into Kelantan, and they are likewise but poorly developed south of Pahang in Negri Sembilan. They are everywhere associated with the Arenaceous Formation of the Main Range Foothills, quartzites, quartzite-conglomerates, shales, cherts, phyllites, quartz- and mica-schists, which may be either Triassic according to Scrivenor (1911, 1931) or perhaps older than the adjacent Permocarboniferous shales and limestones according to Service, Alexander, and the writer (*Ann. Rep.*, 1940, para. 39 ; 1939, 1946). In some areas they lie partly on the Main Range granite (Text-fig. 1).

A few bands of nickel-chromium-bearing serpentine are found amidst the schists in the Telom and Jelai Kechil valleys. Farther south in the Raub District a large elliptical mass of similar serpentine is partly enclosed by, and also partly surrounds the schists.

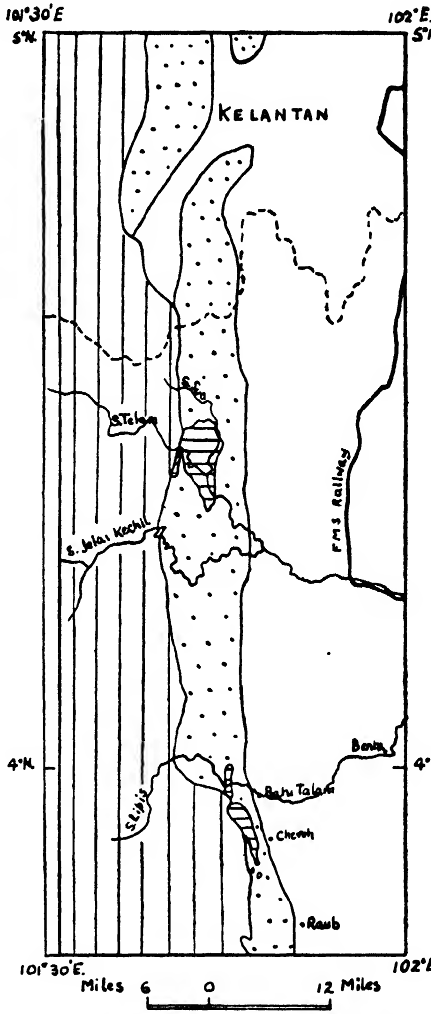
2. PETROLOGY

The petrology of the Amphibole-Schist Series has been described by Scrivenor (1911), Willbourn (*Ann. Rep.*, 1933–34), and the writer (1939) ; a summary will suffice here.

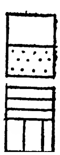
The Series in north-west Pahang consists preponderantly of actinolite-schists together with some epidote-schists and varieties carrying notable amounts of micas and chlorite. They are all completely crystalline, of very fine to moderately coarse grain, hard, compact, and non-porous, brittle and splintery, thinly and strongly foliated. They have a silky texture, are usually coloured dark blue-green or grey-green (actinolite-schists), greyish-white (tremolite-schists), yellowish green or yellow (epidote-schists) ; colour-banding is common and is determined by the mineral composition of the rocks. Hornfelses occur but are not abundant.

The most common mineral species present are actinolite, tremolite, epidote (pistacite, zoisite, clinozoisite, and sometimes orthite), felspars (albite, albite-oligoclase, and orthoclase), chlorite and mica in some varieties, and quartz. Garnet occurs in schists from the Sungei Lanau, Anak Telom, and elsewhere, but it is not widely developed. Anthophyllite-schist lies near granite at Jeram Sekat Tapak, Sungei Telom; pyroxene-bearing schists and hornfels occur around Cheroh. The accessory minerals inclue black iron ores (ilmenite and magnetite) and sulphides (pyrite, pyrrhotite, and occasionally traces of chalco-pyrite) Graphite dust occurs in some schists.

The schists comprise alternating folia of dark and light components. Common combinations are bands predominantly of amphibole, quartz and amphibole, epidote and quartz, graphite veinlets, and so on. Generally, they have suffered considerable crushing, contortion, and plastic deformation indicated by shattering, sigmoidal folding, and flow-structure on a microscopic scale, and by intense folding seen in larger exposures. In the Telom valley, for example, amphibole-schists have become corrugated along axes lying nearly horizontal concertina-wise one above another.



TEXT-FIG. 1.—Geological Sketch-map of North-West Pahang, Malaya.



Permocarboniferous and intrusions.
Arenaceous Formation of the Main Range Foothills.
Amphibole Schist Series (including Serpentine).
Main Range Granite.

Crystalline schists similar to those described above have not been recorded from other parts of Malaya. Rastall (1931) has described the so-called Terendum Schists (banded biotite-garnet-pyroxene-schists) of the Kinta valley ; Ingham and Willbourn (1933) almost identical rocks and hornblendic varieties from Kramat Pulai south of Ipoh. Scrivenor (1931) has mentioned biotite-actinolite-pyroxene-schist at Kramat Pulai. Savage (1937) has mapped calc-silicate-hornfels and schists in the Sungei Siput District, Perak ; Ingham (1938) similar material along the Cameron's Highlands Road east of Tapah. Roe (*Ann. Rep.*, 1937–1940) has recorded the same type of metamorphosed calcareous rocks from Ulu Selangor and the writer has also found them in roof-pendants in granite in the Cameron's Highlands District of Pahang. None of these rocks, however, is identical with those of the Amphibole-Schist Series of north-west Pahang.

3. Petrogenesis

The rocks of the Amphibole-Schist Series have been considered to be metamorphosed dolerite (*Ann. Rep.*, 1933 and 1937), or altered impure limestone, calcareous shale, or calcareous tuff of Permo-carboniferous age (*Ann. Rep.*, 1934 and 1938), and there still exists considerable doubt concerning their mode of formation.

Analyses of four rocks of this series from the Raub District (Richardson, 1939) are given in Table I on p. 244.

The parental rocks were either (i) originally rich in iron, magnesia, and lime, or (ii) considerable quantities of these radicals, together with alkalis, were introduced during metamorphism. Possible parental rocks might be :—

(i) Dolomitic limestones, calcareous and magnesian shales, and tuffs belonging to the Permocarboniferous Formation.

(ii) Basic igneous rocks including lavas of the Pahang Volcanic Series.

(iii) Sedimentary rocks, belonging either to the Foothills Formation or to the Permocarboniferous Formation, influenced by FeO-MgO-CaO-rich effluents from ultrabasic igneous rocks.

The variable, but generally high, percentages of Al_2O_3, Fe_2O_3, MgO, and CaO in the schists and hornfelses, and the presence of notable amounts of Na_2O and K_2O accord with the view that the parental rocks were a sedimentary series of calcareous argillites, rather basic tuffs, and impure dolomitic limestones in which also contemporaneously interbedded lavas and later intrusive dyke rocks may have occurred. Some bands were CaO-rich, others highly magnesic or dolomitic ; some were felspathic (arkosic or tending towards

grauwacke), others highly ferruginous. The relative abundance of TiO_2 suggests that some of the constituents were derived from basic igneous rocks, either intrusive (e.g. diorites and dolerites) or volcanic (e.g., from andesitic or basaltic pyroclasts or lavas). The presence of

TABLE I

ANALYSES OF ROCKS OF THE AMPHIBOLE-SCHIST SERIES, PAHANG
(Analyst: G. M. Harral, Malayan Geological Survey)

	Tremolite-Schist (S. Cheroh)	Diopside-Tremolite-Hornfels (S. Chembatu)	Epidote-Schist (S. Lipis)	Epidote-Schist (S. Lipis)
SiO_2	48·87	43·87	44·05	51·35
Al_2O_3	10·33	18·56	15·06	14·02
Fe_2O_3	4·15	2·14	7·19	2·57
FeO	10·86	4·08	3·18	5·20
MgO	10.31	10.86	5·25	8·67
CaO	5·32	12·74	20·64	9·30
Na_2O	2·91	0·41	trace	2·43
K_2O	1·39	1·61	1·71	2·71
$H_2O +$	4·28	5·32	1·20	1·95
$H_2O -$	0·22	0·23	0·25	nil
CO_2	0·15	0·13	trace	nil
TiO_2	1·25	0·18	1·09	1·31
ZrO_2	nil	nil	nil	nil
P_2O_5	nil	nil	nil	nil
Cl	trace	0·01	0·02	0·01
F	nil	nil	0·03	nil
S	0·04	0·04	nil	0·17
MnO	0·14	0·08	0·12	0·14
BaO	nil	nil	nil	nil
NiO	trace	0·05	trace	trace
Cr_2O_3	trace	0·15	0·06	0·04
Pt	nil	nil	nil	nil
Au	nil	nil	nil	nil
	100·22	100·46	99·85	99·87
Less O = Cl + F + S	0·02	0·02	0·02	0·09
	100·20	100·44	99·83	99·78
S.G.	2·87	2·96	3·24	2·93

very small amounts of NiO and Cr_2O_3 can be explained by assuming that fragments of NiO-Cr_2O_3-bearing serpentine or of some other ultra-basic rocks were incorporated along with the pyroclasts. A serpentine-bearing rhyolite-tuff has been found by the writer in the Sungei Serau valley, north-west Pahang. The absence of P_2O_5, however, is surprising, if indeed basic and ultra-basic rocks have contributed to the original material of the Amphibole Schist Series. It may have

become completely leached out during sedimentation of the parental rocks.

The absence of ZrO_2 suggests either (i) that nothing has been added by effluents from granitic sources, or (ii) that any granitic material introduced was wholly devoid of zirconia.

The suggested composition of this presumed parental sedimentary series resembles rather closely that postulated by Scrivenor for some of the Schists of the Lizard Peninsula, Cornwall. Writing of the hornblendic green schists and quartzose hornblende-schists of the Old Lizard Head Series of Cornwall, Scrivenor (1938, p. 518) has expressed the opinion that those schists containing little or no quartz may have been derived from basic igneous rocks, whereas those with much quartz may have been developed from calcareous sediments. He has stated his belief (op. cit., p. 526) that the great abundance of epidote amongst an area of hornblende-gneiss at Pen Olver and Polledan Cove is due to the complete absorption of calcareous rocks by the precursor of the gneiss.

There seems thus to be some similarity between the conditions postulated by Scrivenor for the formation of the Lizard schists and those which may have obtained in the Main Range Foothills, Malaya, during the development of the Amphibole-Schist Series.

Some bands of amphibole-schist in the Telom and Jelai Kechil valleys seem indeed to be altered dioritic rocks but the majority appear not to have been formed from igneous predecessors.

The presence of small amounts of NiO and Cr_2O_3 in some of the schists and hornfelses from the Raub District, the association of the Amphibole-Schist Series with important serpentines between Cheroh and Batu Talam and the occurrence of small lenticular intrusions of serpentine in the Telom and Jelai Kechil valleys suggests that these radicals may have been introduced directly from ultrabasic rocks. Analyses carried out by the chemists of the Malayan Geological Survey in 1938–39 showed that traces of NiO and Cr_2O_3 occur also in some of the phyllites associated with the amphibole-schists, and it seems more probable that these unusual constituents of original argillites have been introduced by migrant effluents from igneous rocks than that they are derivatives of normal denudation and sedimentation.

If the NiO and Cr_2O_3 present in the schists and hornfelses were indeed introduced from serpentine they may just possibly have been accompanied by an FeO-CaO-MgO effluent which could have basified a series of sediments undergoing metamorphism. The fact that amphibole-schists are best developed where serpentines are least abundant (Telom valley) and vice versa (Cheroh and Batu Talam areas) militates against the probability of this suggestion, however.

The Cheroh Schists might possibly be the end-products of the contamination of ultrabasic magma by mixed calcareous, argillaceous, and arenaceous rocks, reminiscent of the process suggested by Scrivenor for the formation of the Lizard schists. Such a transformation may have been aided by later migrant effluents from the Main Range granite.

Professor H. H. Read (communication to the writer) has commented upon the mixed nature of the metamorphic suites present in the Amphibole-Schist Series. He has suggested that the association of minerals such as actinolite, tremolite, anthophyllite, garnet, micas, and chlorite in one and the same metamorphic series may possibly indicate its having undergone a history of polymetamorphism such as he has established in Unst, Shetland Isles. No details of such changes have, however, yet been worked out.

The outstanding features of the series will first be summarized and then the facts *pro* and *contra* their being normally metamorphosed sediments will be set out.

1. The Amphibole-Schist Series is, so far as is known, confined to outcrops in the Main Range Foothills and between these Foothills and the Main Range granite. Serpentine is virtually confined to this same region. Nowhere do such schists appear in the main outcrop of the Permocarboniferous Formation (limestones, shales, and tuffs) which is generally believed to contain the only calcareous rocks in Malaya. The bulk of them do not lie in contact with the granite but at some considerable distance (commonly 2 to 3 miles) east of it.

2. No transitional types between thorough-going schists and their possible parental rocks have been found.

3. Some few bands are probably metamorphosed igneous rocks. The bulk of the schists, however, have no relict igneous features.

4. Strongly sheared and brecciated serpentine containing NiO (pyrrhotite) and Cr_2O_3 (chromite and picotite) is associated with the schists, particularly between Batu Malim and Cheroh. It has never been found passing into them but has, wherever the contact has been examined, a sharp boundary with the schists.

5. Amphibole-schists (predominantly actinolitic varieties) in the Sungei Sua are interbedded with mica-schist, quartz-schist, and graphitic varieties, and the whole packet of foliated rocks is sharply folded into groups of asymmetric anticlines and synclines pitching about N.N.W. or S.S.E. Canoe-shaped outcrops of mica- and quartz-schists enclosed in the main amphibole-schist belt and vice versa are common in the Telom and Jelai Kechil basins. Elongate and elliptical belts of quartz-schist and phyllite are enclosed in amphibole-schist in the Cheroh area.

The folding together of interbedded amphibole-, mica-, and quartz-schists and phyllites proves that the parental rocks of the Amphibole-

Schist Series were layered. They must, therefore, have been either sills or lava sheets, or beds of sedimentary or pyroclastic material.

If indeed the rocks of this crystalline series were formed by the metamorphism of Permocarboniferous shales, tuffs, and limestones then we might well expect that such rocks would have become converted into similar amphibole-schists when subjected to heat and pressure metamorphism. The following examples indicate that this has not been so.

1. Quartz-schists and phyllites, practically identical with those interbedded with the amphibole-schist in the Sua-Kerla-Tempoi basin, occur at Cameron's Highlands. Calc-silicate-schists and hornfels, obviously altered impure limestones and calcareous shales, are associated with them, but they show no similarity to the Telom, Jelai Kechil, and Raub amphibole- and epidote-schists.

2. Limestone, phyllite, and shale lie in the Sungei Telom near the middle of the Main Range Foothills. Considerable pressures have been exerted in this area but these sediments have suffered little intensive alteration.

3. Magnesian limestone, containing up to 5 per cent of clay residues, interbedded with calcareous shales flanks a suite of granitic and hybrid rocks at Ulu Gali in the western foothills of the Gunong Benom Range (Richardson, 1939). The limestone has become marble ; some of the shales have become calc-silicate-schist, but no amphibole-schist such as that herein described has been formed.

4. A group of limestone hills sits on granite around Lenggong, Perak valley. Some bands have become rich in secondary silicate minerals.

5. Dolomitic limestone at the Tui Gold Mine, Pahang, partly surrounded by granite at no great distance away ; and impure magnesian limestone containing variable amounts of clay and pyroclastic material interbedded with rhyolite-andesite-tuffs, andesite-tuffs, and calcareous shales flanking the Chegar Perah-Pulai porphyry intrusion have suffered no serious metamorphism.

6. A more spectacular example is afforded by the tin mines at Pinyok and Teng Gading, Patani Province, South Siam. Here, a natural amphitheatre of limestone underlain by shale, is heavily intruded by granite, and is enclosed at a considerable distance by other granite ranges. The limestone has become crystalline and some of the shale is hardly altered, but a band some 200 feet thick of what must have been clayey dolomitic limestone or magnesia-rich and lime-rich shale has been converted into coarse grained pyroxene- and garnet-hornfels. It has been soaked by effluents from tin-bearing granite and now contains minute crystals of cassiterite in payable quantities (writer's unpublished field-notes). There are, however, no amphibole-schists.

7. The natural amphitheatre of crystalline limestone hills at Kramat Pulai, Perak (1933), has been invaded by granite and aplite intrusions. A band of shale interbedded with the limestone has been converted into banded biotite-, garnet-, and pyroxene-schist together with some hornblendic biotite-actinolite-pyroxene-schist ; much of the limestone has been replaced by fluorite and scheelite (worked out in 1940) but no rocks identical with the Pahang amphibole-schists have been produced.

It is clear from these examples that, so far as the writer has been able to ascertain, pressure alone, heat alone, or simple combinations of the two together have not converted calcareous shales, impure limestones, or calcareous rhyolite-andesite-tuffs, andesite-tuffs, and agglomerates into the characteristic amphibole-schists found in Pahang. No satisfactory answer can yet be given to the question : " What special conditions of temperature, pressure, and rock composition were necessary to produce these rocks ? " It seems probable, however, that their restriction to a zone lying between the massive block of the Main Range Foothills and the Main Range granite which forms the tectonic spine of Malaya may indicate that some specific conditions of pressure, at least, did obtain. It is possible, for instance, that the rocks suffered particularly severely from a sort of nutcracker compression, and the presence of extraordinarily contorted, plastically deformed, massive, hard quartz-schists west of Cheroh supports this view (1939). In addition, repeated and perhaps interrupted shearing, together with migrations of granitic material, may have taken place along the margin of the Main Range granite. Tremolite-hornfels occurs with the Cheroh schists, although it is wholly subordinate in amount to the normal actinolite-, tremolite-, and epidote-schists. No hornfelses have been found in the Telom and Jelai Kechil basins. It is uncertain whether these hornfelses were formed by heat derived from the serpentine or from the granite.

The serpentines found amongst the schists appear originally to have been nickel- and cobalt-bearing peridotites, hypersthene-pyroxenites, and saxonites judging from the presence of completely serpentinized relict mineral structures in them (Richardson, 1939). It is just possible that a sort of FeO-CaO-MgO front migrated from the ultra-basic igneous rocks into adjacent sedimentary and pyroclastic strata, and thus basified them.

The serpentines have suffered considerable shearing and compression ; quartz-schists adjacent to them have obviously been plastically deformed. It is possible, therefore, that the conditions of compression, hypothetical FeO-CaO-MgO migration and any superimposed conditions of heating and base migration from the Main Range granite in the vicinity may have combined to produce the Amphibole-Schist Series.

It is significant, however, that pyroxenite present in the western foothills of the Gunong Benom Range, Pahang, reacted upon by granite, has been converted into a suite of hybrid rocks including orthoclase-biotite-pyroxene-gabbro, syenite, and monzonite and an end-product which is biotite-hornblende-granite (Richardson, 1939). No amphibole-schist was formed during the reactions.

The distance of the parental rocks from the granite may have been of special importance. The Telom valley schists impinge upon the Main Range granite and extend laterally for some five miles east of it ; many of the Jelai Kechil valley schists lie at least two miles east of the granite ; the Cheroh schists lie in places on the granites but most of them are also east of it. There is no reason to believe, however, that granite occurs beneath the schists at exceptionally shallow depths, for many argillites, occurring in these zones display only a phyllitic banding without spotting or flecking, and little or no secondary mica.

The age of the Amphibole-Schist Series is not definitely known. The parental rocks may have been sediments or pyroclastics of the Permocarboniferous Formation or they may have belonged to the Arenaceous Formation of the Main Range Foothills, together with some igneous bands. The metamorphism to which they have been subjected presumably accompanied the major orogeny responsible for the structural development of British Malaya. It is believed to be of Cenomanian age.

The writer thanks Mr. J. B. Scrivenor and Mr. E. S. Willbourn who have read and commented upon this paper.

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REVIEWS

GEOLOGICAL EXPEDITION OF THE UNIVERSITY OF AMSTERDAM TO THE LESSER SUNDA ISLANDS IN THE SOUTH-EASTERN PART OF THE NETHERLANDS EAST INDIES, 1937. Under the leadership of H. A. BROUWER, Professor of Geology at the University of Amsterdam. *Nieuw Verbond Noord-Hollandsche Uitgevers Maatschappij, Amsterdam.*

Vol. i, 1940. Geologie des Mollogebirges und einiger benachbarter Gebiete (Niederländisch Timor): D. TAPPENBECK. Geological Investigations in N.E. Netherlands Timor: A. L. SIMONS. Neue Blastoiden aus dem Perm von Timor (mit einer Beitrag zur Systematik der Blastoideen): J. WANNER. Neue Permische Krinoiden mit Angaben über deren Fundstellen im Basleo Gebiet (Niederländisch Timor): F. A. H. W. DE MAREZ OYENS.

Vol. ii, 1940. Geological and Petrological Investigations on alkali and calc-alkali rocks of the islands Adonaria, Lomblen, and Batoe Tara: H. A. BROUWER. Geological Investigations in the south-western Moetis region (Netherlands Timor): W. P. de ROEVER. Geologische Untersuchungen im Distrikt Amfoan (Nordwest Timor): J. H. VAN VOORTHUYSEN. Neue Permische Lamellibranchiaten von Timor: C. WANNER.

Vol. iii, 1941. Geological Investigations in the Miomaffo Region (Netherlands Timor): F. P. VAN WEST. Sur la composition et la genèse du bassin central de Timor: D. L. DE BRUYNE. Geological Investigations in West Wetar, Lirang, and Solor: J. D. DE JONG.

Vol. iv, 1942. Geological Investigations in East Wetar, Alor, and Poera Besar: J. HEERING. Neue Beiträge zur Gastropodenfauna des Perm von Timor: C. WANNER. Olivine-basalts and their alkaline differentiates in the Permian of Timor: W. P. DE ROEVER. Granodioritic intrusions and their Metamorphic Aureoles in the Young-Tertiary of Central Flores: H. A. BROUWER. Hydrothermal Metamorphism in the Lowo Ria Region: J. D. DE JONG. Summary of the Geological Results of the Expedition: H. A. BROUWER.

In a brief preface dated January, 1940, Professor Brouwer says that some of his students took part in the expedition to carry out field-work necessary for their doctorate theses, which therefore constitute a large part of the volumes totalling 1,546 pages. The book comprises seventeen contributions, ten being in English that reflects the high standard of education in modern languages at Dutch universities.

The production of the text and maps is excellent, but some of the photographs might be clearer. The micro-photographs are very good. It will be seen from the dates that the last two volumes must have been produced during the German occupation of Holland. In 1946 some " separates " reached England ; but it is believed that the complete work has not been available before.

To write an adequate appreciation of the work done by Professor Brouwer and his party during this expedition would require more space than is available, so only brief comments can be given. The islands selected for investigation form that part of the Inner and Outer Banda Arcs where they appear to have either been squeezed together so that the Portuguese portion of Timor is close to Alor and Wetar ; or Timor may have been pushed northwards towards the inner row of islands by the Sahul Shelf drifting up from the south. Land first appeared on the site of Timor as two rows of islands resulting from folding, parallel to the present axis of Timor and comparable to the two rows of islands in the Tenimber and Kei groups of to-day. With further elevation a central basin was formed in which young Tertiary and Pleistocene rocks were deposited. This central basin is described by de Bruyne. One result of the earth movements was that the axis of volcanic action advanced northwards, being now confined to the Inner Banda Arc, the isolated volcanic island Batoe Tara, and two foci of submarine activity in the Flores Sea ; while the earlier volcanic activity of Timor has been reduced to mud-volcanoes.

The greater part of the work of the expedition was in Dutch Timor, where five selected areas were studied, most of them in the middle of the country, but one, described by Simons, close to the Portuguese border. The non-metamorphic Permian and Mesozoic rocks dealt with are : (1) the Kekneno Series ; (2) the Sonnebait Series ; (3) the Fatoe Complex, and (4) the Palelo Series. The Kekneno Series is mainly composed of shales and sandstones. Some are Triassic, others Lower Permian. The Sonnebait Series consists of Permian and Mesozoic marine deposits, and covers a wide area. It includes red, abyssal clay, believed to be of Upper Cretaceous age, with radiolaria, manganese nodules, and abundant teeth of sharks resembling *Lamna*. The Fatoe Complex is the designation for blocks of limestone thrust over younger rocks. Their age is Permian, Triassic, and Liassic. " Fatoe " is the Dutch romanization of a local word meaning a steep hill, not necessarily of limestone. In the papers on Timor we also find " Noil " and " Nono ", both meaning " river ". The Palelo Series is divided into two parts ; the lower is mainly radiolarian chert, volcanic breccia and other igneous rocks ; the upper and more extensive part contains a *Globotruncana* Upper Cretaceous fauna, a possible Upper Jurassic fauna, and perhaps Eocene

rocks. In the Palelo Series lava flows are abundant in the Mollo region.

Owing to the authors' districts in Timor being separated, it is not always easy to correlate their descriptions from the texts, but the following table, based on them, may be helpful :—

	Mollo (Tappenbeck)	N.E. (Simons)	Moetis (de Roever)	Amfoan (Voorthuysen)	Miomaffo (van West)
Cret.	Palelo Sonnebait		Sonnebait		Palelo Sonnebait
Jur.	Palelo		Fatoe Sonnebait		Palelo
Trias	Fatoe Kekneno Sonnebait	Fatoe Kekneno Sonnebait	Fatoe Kekneno Sonnebait	Fatoe	Fatoe
Perm.	Fatoe Sonnebait ?	Fatoe Sonnebait	Kekneno Sonnebait	Sonnebait	Palelo

De Bruyne mentions Fatoe and Sonnebait rocks in the Central Basin as well as Plio-Pleistocene rocks. In addition to the above, there is an Ophiolite-Spilite-Complex of doubtful age. A description is given by de Roever in vol. ii, pp. 150–156, of this complex in the Moetis region. An Ofoe Series " is of younger Mesozoic age, and shows facial resemblance to the contemporaneous part of the Sonnebait series " (vol. iv, p. 368).

In addition to the separate papers on Permian fossils, there is an appendix to Simons's regional paper, on Permian ammonoids, by de Roever. The palaeontological papers are well illustrated. Brouwer, in his " Geology of the Netherlands East Indies " (1925, p. 15), reports that " immense collections of blastoids, belonging mostly to *Schizoblastus*, have been made " . . . " in beds of which the greater part is undoubtedly properly referred to the Permian."

The *Globotruncana* foraminiferal fauna is well illustrated by Tappenbeck (vol. i, plate vii). He also gives (pp. 40, 41) a table showing the succession of rocks from Cretaceous to Plio-Pleistocene in three districts.

There is a wealth of detailed description of crystalline schists and igneous rocks. Among the former are graphitic schists in van West's area. He found that some crystals of felspar and tourmaline had cores of graphite (vol. iii, pp. 63 seq.). De Roever (vol. ii, p. 263), introduces a new name " poenite ", based on a river Poene, for a rock with laths of orthoclase and subordinate olivine in a glassy base,

comparable with verite of southern Spain. In vol. iv he describes the adularization of Permian olivine basalts and compares with them poenite, of which he gives an analysis showing 8·97 per cent K_2O and 1·39 per cent Na_2O.

Of the Inner Banda Arc the following islands were visited : Flores (eastern part), Solor, Adonara, Lomblen, Batoe Tara (north of Lomblen), Alor, Lirang, and Wetar. They are all volcanic, but in Flores granodiorite with metamorphic aureoles is described, and *Globigerina* limestone was found to be intercalated with andesite and dacite in Wetar (de Jong, vol. iv, p. 343). The same author shows in plate ix, fig. 2, a remarkable felspar crystal with microliths arranged like iron filings at the poles of a magnet. In vol. ii Brouwer contributes an important paper on the alkali and calc-alkali rocks of Adonara, Lomblen, and Batoe Tara. On the last he found leucite-basanite, leucite-basalt, and leucite-tephrite. De Jong and Heering contribute interesting remarks on unresorbed crystals of hornblende in lavas that were submarine.

The fourth volume concludes with a summary of the results of the expedition by Brouwer, with a coloured map on the scale 1 : 1,000,000. This is a great help in assimilating the work of the several authors, whose areas in Timor are shown in a text-figure. The sections on structure and tectonics, however, are not easy to grasp, largely because the information obtained is not complete for the purpose. On p. 387 he refers to earlier publications in which he mentioned relative movement towards the Australian continent, and says : " The horizontal movement of the rows of islands has been emphasized by several authors, more particularly by those who are in favour of continental drift," but is not the crux of the question whether the islands are moving towards a stationary and resistant Australia, or whether a drifting Australia is pushing the islands ? There is little in the regional papers to help the reader to understand the tectonics of Dutch Timor. A section on p. 380, vol. iv, seeming to indicate overfolding and thrusting towards the south-east, is of some assistance. The coloured map at the end of the summary gives all the pre-Tertiary series and complexes ; but the table above shows that some of them have a long range in age. A general map showing Permian, Trias, etc., would have been more informative, but perhaps was impossible. Tappenbeck's regional map is the best in that respect.

Professor Brouwer and his party have earned our gratitude for a very fine piece of work, and it is to be hoped that at no distant date they may be able to extend their researches to Portuguese Timor, at present a geological blank, and to the other islands of the Outer Banda Arc.

J. B. S.

GÉOLOGIE DU GRANITE. By E. RAGUIN. pp. 211, with 46 figs. Paris, Masson et Cie, 1946. Price 360 *frs.*

It has been said that far too little attention has been paid in the past to the writings of French geologists on the subject of granite. The recent discussions on granitization have aroused renewed interest in their ideas, and a modern work on the geology of granite by so eminent a French geologist as Professor Raguin, Director of the Geological Survey of France, will, therefore, be very welcome in this country. The aim of this book is to review the evidence of geological observations on the origin of granites. Professor Raguin has done good service by trying to give a broad view of the geological evidence bearing on granite of all kinds. He states the problems which await solution, and frankly admits that to few of them can precise answers be given, but he does allow himself to discuss theories and suggest what his own opinions are on such subjects as the relationship of granitization to metamorphism, and of granite to orogeny and, in the concluding chapter, on the problem of the formation and emplacement of granite.

The geological observations are assembled in the first eight chapters. There is a general definition of granite, its mineralogical, chemical, and textural features. Two main categories are recognized, the anatectic granites with vague borders, and the granites of the limited massifs with sharp boundaries (massifs circonscrits). Of the latter the author writes that they *appear* to have effected intrusion among the enclosing rocks, but that this may be only an appearance. They are referred to later for convenience sometimes as " intrusive ". Their emplacement is discussed in the final chapter of the book, and remains one of the unsolved problems. The earlier chapters deal with evidence of assimilation, structure of granites of both categories, differentiation, contact metamorphism and the granite aureoles, the associated dykes, and alteration and crushing. In later chapters granitic metallogeny and the radioactivity of granite are discussed.

Dykes associated with granites fall into three groups : aplites and pegmatites, lamprophyres, and porphyries (with microgranites). (Hydrothermal veins are discussed in the chapter on metallogeny.) It is noted that lamprophyres and porphyries are associated only with the granites of the limited massifs, but not with anatectic granites. Aplites and pegmatites are associated with granites of both categories, but where pegmatites are frequent porphyries are scarce and *vice versa.* The dykes of porphyry, microgranite, and lamprophyre are discussed further in the chapter on granite and vulcanicity from the point of view of evidence for close relations between such dykes, directly associated with granite, and volcanic rocks. The author finds plenty

of evidence for some kind of relationship between granite and vulcanicity, but not much for the idea that vulcanicity at the surface is directly connected with plutonic rocks in depth. As regards time relations, the most frequent order is vulcanicity followed by plutonic " intrusion " and not the reverse. However, the very positive claims of W. Klupfel [1] for the constancy of this order are not upheld.

The chapter on metamorphism is important as being an up-to-date statement of the views of French geologists on regional metamorphism or " general " metamorphism as the author prefers to call it. The views of Termier and of Jung and Roques are rather fully discussed. It seems agreed that there is a connection between granite and general metamorphism, but it is difficult to define. In the lowest zone of metamorphism the lower gneisses of the crystalline schists and the migmatites may shade into one another. On the other hand, " general " metamorphism is in some degree independent of granitization. General metamorphism seems to have preceded the orogenic movements, but the rise of granite has accompanied or followed them.

This question of the relationship between the granites and orogeny is the subject of another chapter, in the course of which the theories of C. E. Wegmann and of F. E. Suess are compared. One looks to the final chapter on " The problem of the formation and emplacement of granite " to find where the author would stand were he to enter the present controversy on the granite problem in this country. The opinion is clearly stated that granite has passed through a liquid state, and is not a metamorphic rock, but the author qualifies this statement. The passage of granite through a liquid state may have taken place gradually. Perhaps at no time has the whole mass been simultaneously liquid. For some granites even the fraction of the whole mass liquid at any one time has always been small. In such a case the process would approximate to metamorphic recrystallization. At the temperature range indicated by the granite-forming minerals, there can be no simple fusion, but liquefaction would be facilitated by solvents (including water vapour) which could have been eliminated at the end of the solidification.

Diffusion in the solid state as advocated by Perrin and Roubault, and by Backlund is not accepted, and the author thinks the difficulty of explaining the presence of large feldspars in inclusions and country rock as well as in the granite is not insuperable. At the time of crystallization of these feldspars the granite would not be wholly liquid and the country rock, impregnated with solutions, would not itself be in a very different physical state.

It is difficult to find a precise definition of the sense in which the

[1] *Ueber die Altvulkane und die Neuvulkane und ihre Abstammung. Zentr. f. Min.*, Abt. B., 1941, pp. 230, 249, 281, 313.

author uses the term " granitization ", but it is doubtful if he would limit it to the extent of H. H. Read's definition of it as that process " by which solid rocks are converted to rocks of granitic character without passing through a liquid stage ". On the mode of formation of granite, the author refers to the ideas of Auguste Michel-Lévy, Lacroix, Termier, and Sederholm, and seems to accept wholeheartedly the process envisaged by Sederholm for the migmatites as applicable to the anatectic granite masses, and as having proceeded on a vast, almost planetary, scale, and over periods of geological time ranging into millions of years. For the mode of emplacement of the " intrusive " granites he has really no solution to offer. Neither mechanical intrusion, nor assimilation, nor contact metamorphism, is adequate. There must be unknown factors at work, and some possibilities are suggested.

The final problem in this concluding chapter is the chemical composition of granite. Why, the author asks, does the process of granitization lead to rocks whose composition is always within rather definite limits ? Granitization of any considerable body of rock in the earth's crust results in a notable increase of alkalis, and also a homogeneity of composition throughout the mass which is independent of textural and to some extent of mineralogical differences within the area affected. This homogeneity of granites is in sharp contrast to the banded character of many basic intrusions. The author does not believe it is attained in a magma basin by assimilation and diffusion, but that it must be initiated in a physical state akin to that of migmatites. As for the problem of individualization, he considers and rejects Termier's eutectic theory and offers an explanation based on the conception that after a certain minimum content of alkalis necessary for complete fusion is attained excess constituents carried by the mobile emanations travel through and out of the granitized area. Here again the process can be better imagined as applicable to the anatectic granites than to those of the limited massifs, and the author concludes by underlining the great and fundamental problems of the geology of granite which remain unanswered.

W. C. S.

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The Composite Intrusion of Sròn Bheag, Ardnamurchan

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INTRODUCTION

MUCH attention has been paid to composite dykes and sills during the present century, and accepted definitions of the term " composite " centre about that of Daly (1933), who has stated that composite dykes are formed by successive injection of chemically differing melts into the same fissure which widens to receive them.

Resulting from his work in Skye and elsewhere, Harker (1904), found that the time order of injection was normally from basic to acid. Subsequent research has confirmed the truth of this generalization whilst bringing to light some abnormalities in the way of field relations. These abnormalities are well shown in the instance to be considered.

FIELD RELATIONS

The Sròn Bheag, which forms the headland of the faulted Mesozoic outlier of Maol Buidhe, lies about a mile and a half south-west of Kilchoan Jetty in southern Ardnamurchan. The headland is largely determined as a topographical feature by a composite dyke intrusive into sandstones and flags of Inferior Oolite age. It is cut by cone sheets of the Achosnich Centre (Centre 2).

The field relations and petrology of the intrusion have been briefly described in the Geological Survey Memoir (Richey, Thomas, and others, 1930). Subsequent field work has fully confirmed the accuracy of the Survey mapping. In the present contribution attention is focused on the relations between members of the composite intrusion and on certain new features which have emerged from detailed study.

(*a*) *Components of the Intrusion*

The intrusion consists of three members, two acid bodies flanking a central quartz-doleritic body. The acid masses parallel the basic, and can be traced inland for some 180 yards for the western mass, and 220 yards for the eastern one, which spreads out laterally at its

termination as a sheet in the sandstones and flags. This sheet is traceable eastwards for about a hundred yards. The average width of these bodies is 90 feet on the east and 60 feet on the west.

The quartz-dolerite outcrops over a length of 460 yards and cannot be traced very far north above the Trigonometrical Station on Maol Buidhe. Its average width is 280 feet.

Much later in date, and apparently unrelated genetically to the composite intrusion, is a basic dyke intruded into the centre of the quartz-dolerite. This dyke outcrops over a length of 50 yards, and cuts the cone sheets. From its general relations and petrographical characteristics, it may perhaps be referred to the Mull Dyke Swarm. It will not be further considered in the present account.

The whole composite intrusion has a general north-westerly trend, and is exposed over a vertical interval of nearly 500 feet.

(*b*) *The Acid Bodies*

The contacts with the country rock show chilled, though not particularly glassy, margins whilst the sandstone is thermally metamorphosed for a short distance from the contact. The temperature of the intrusion does not appear to have been very high since no inversions from tridymite or higher forms of quartz can be seen in thin section of the hardened sandstone. The contact, where visible from beneath shingle or vegetation, is well defined and sharp.

As a contrast the contact with the quartz-dolerite is very diverse, sharp in one place, yet only a few feet away showing a gradual transition. Locally it is brecciated, whilst acid veins and stringers penetrate the basic mass. Xenolithic material derived from the basic member may be seen along the contact, more particularly on the western acid flank.

Of special interest are small dyke-like masses occurring close to the acid—basic contact. The most prominent one may be taken as a typical example. This is situated in the eastern acid body, and is visible just above low water mark in the cove 250 yards south-west of MacDiarmid's Cove. Some ten yards in length and nine inches wide, it is situated about a foot from the contact. For the greater part of its course it is completely enclosed in the acid rock that takes a westerly turn at its seawards end, tailing off into the quartz-dolerite in a breccia of fragmented material of its own composition, together with some brecciated acid material. This is the plane of motion commented on by Mr. Campbell Smith on the occasion of the excursion of the Geologists' Association in 1933 (see Richey, 1933). In the hand specimen the rock is dark and fine textured. Detailed investigation suggests that it is a chilled marginal phase of the quartz-dolerite that has undergone some subsequent modification by the acid magma.

(*c*) *The Quartz-dolerite*

In the field, the main basic intrusion shows, besides the contact phenomena already noted, an ill-defined primitive columnar structure along which acid material has penetrated more or less extensively. These columnar structures are rendered less obvious by the development of a more recent system of rectangular jointing. Where the quartz-dolerite directly contacts the country rock, i.e. in the region of Maol Buidhe, it suffers a reduction in texture which leaves the rock crystalline and not glassy. Over a vertical interval of 500 feet there is no great change in composition, the quartz-dolerite still preserving its features, including a patchy distribution of acid interstitial material which may assume megascopic dimensions.

Sequence of Events

From the foregoing it can be seen that the basic—acid order of intrusion holds, although the intrusion departs from established type in showing basic rock flanked by acid. The general sequence of events can then be tabulated as follows:

1. Injection of quartz-doleritic magma which, as far as is evident in the field, failed to reach the Tertiary land surface. It cooled sufficiently to permit of the development of primitive column structures.
2. After a comparatively short interval the acid magma was injected in a flanking relation to the quartz-dolerite. This also failed to reach the Tertiary land surface, and the eastern mass spread out as a sheet into the Inferior Oolite sandstones and flags.
3. After a considerable lapse of time the Outer Cone Sheets of Centre 2 were injected in transcurrent relationship to the composite dyke.
4. This was followed at a very much later date by the unrelated basic dyke.

Petrology of the Basic Components

(*a*) *Main Quartz-dolerite*

In the hand specimen the rock is of a dark brown to green colour, and its major constituents are megascopic. Of particular note is the sporadic distribution in veinlets and patches of a more acid mesostasis.

Examination in thin section shows, in some slices, sub-ophitic relations of felspar and pyroxene, and in this respect the texture cannot be said to differ from that of a normal dolerite, although, as has been stated, there is a reduction in texture where the rock directly contacts the sandstone and flags above the upward limit of the acid bodies.

Two pyroxenes are present, which in order of crystallization are subsequent to a part of the calc-alkali felspar, but within its period of

crystallization. The first and dominant pyroxene is a pale brown monoclinic variety. It sometimes takes on a faint lilac tint together with pleochroism that is compatible with a low titanium content. Sahlitic striations are to be seen in some of the hypidiomorphic crystals as is also simple twinning on 100. A feature of this pyroxene, which approximates to enstatite-augite (in the absence of titanium content), is the tendency to positive elongation parallel to the *c* axis.

There is also a tendency for it to aggregate together with plagioclase in radiating groups. Uralitization has affected this pyroxene to a small degree, the alteration taking place marginally and along the cleavages with the formation of a pale green secondary hornblende, granular magnetite, and chlorite. In some cases the amphibole stage is absent, only chlorite and iron ore being present.

The minor pyroxene is rhombic, and is represented by bastite pseudomorphs. Enough of the original characters of the pyroxene remain to infer that it was probably enstatite. At this point it may be remarked that olivine, when present, is only seen in small serpentinized granules, and it would seem that both olivine and rhombic pyroxene have been made over in accordance with the reaction principle enunciated by Bowen (1928), to form monoclinic pyroxene with the elimination in large part of the original minerals.

Both pyroxenes are associated with a titaniferous magnetite: pyrite occurs occasionally, but is secondary in origin. Occasionally pyroxene is in juxtaposition or rimmed with iron ore which, in turn, may be rimmed with a foxy-red biotite. The mica, scattered in small anhedra throughout the section, is almost invariably associated with iron ore either alone or in the above pyroxene-biotite-magnetite sequence. This occurrence of mica, recalls that in the Torran dolerite of Benn an Dubhaich which Harker (1904) has shown to result from thermal metamorphism. In some few cases the biotite is accompanied by chlorite, as well as iron ore, an association nearly paralleled in a basic gabbro of Carrock Fell (Harker, 1894) where pyroxene has been uralitized with the subsequent production of biotite where the uralitic products are in the neighbourhood of magnetite.

Alkali and calc-alkali felspar constitute about 63 per cent of the bulk of the rock on micrometric analysis. Alkali felspar is mainly confined to the mesostasis, and will be dealt with later. The plagioclase has an approximate composition of andesine-labradorite and occurs in long laths with a tendency to stellate grouping. Polysynthetic albite and pericline twins are present, whilst sometimes a combination of albite and pericline twinning is to be seen. Zoning of the plagioclase is not uncommon, the centre being the more calcic portion of the crystal. Some degree of alteration of the felspar is noticeable with the production of granules of epidote and zoisite, also marginal

albitization in a manner reminiscent of certain spilitic rocks. Such alteration is most in evidence in the neighbourhood of the mesostasis. Alkali felspar, very subordinate in quantity and chiefly present in the mesostasis, is represented by sericitic and kaolinized pseudomorphs after a microperthite showing sometimes simple Carlsbad twins.

The general relation of pyroxene to felspar, despite the stellate tendency, is, as has been mentioned, sub-ophitic. The stellate tendency might, in a finer textured rock, be termed variolitic.

The mesostasis is patchily distributed throughout the section, and is acid in character with an abundance of the altered microperthite mentioned above. Where the mesostasis is segregated into veins there is a definite tendency towards the granophyric texture, whilst where it is in contact with the more basic parts of the dolerite an attempt to attain stable equilibrium under the conditions of cooling can be seen in the albitization of calcic plagioclase with the formation of epidote, zoisite, and a little calcite, together with the conversion of pyroxene to a pale green amphibole as well as flecks of a foxy red biotite. The chlorite in the mesostasis has evidently resulted from the decomposition of the melanocratic constituents of the more basic portions of the rock. Quartz occurs as a major component of this acid residue, and is lacking, except as a secondary mineral, in the purely basic portions of the rock. In bulk it exceeds the alkali felspar.

Apart from the iron ores, the principal accessory mineral is the ubiquitous apatite, together with a few grains of secondary sphene.

Altogether, the dolerite agrees well with those of established Talaidh type, and must be reckoned as originating from magma of the non-porphyritic central type (see Bailey and others, 1924).

(*b*) *Basic Xenoliths and Hybrids*

The basic xenoliths, together with the hybrid rock, can be considered together as illustrating stages of xenolithic absorption. Some idea of the transformations involved can be gained. The hybrid is distributed along the acid-basic contact where it is of a merging nature, and differs but little in the hand specimen from the quartz-dolerite. The basaltic looking xenoliths will be described first.

(i) Fine grained, black and with no megascopic constituents, this material shows in thin slice a texture that approximates to the hyalophilitic of Johannsen (1939), and the rock consists of a felted mass of minute crystals and microlites of plagioclase. These plagioclases have, as in the main quartz-dolerite, a tendency to stellate aggregates. They approximate in composition to a labradorite somewhat close to andesine, and show the usual lamellar twinning. No signs of albitization of this felspar were noted. Phenocrysts of a very calcic plagioclase occur sporadically throughout, and show simple albite type twins.

They are characterized by marginal resolution effects in the coarser parts of the rock.

The groundmass consists of a brown glassy material, together with microlites of an augitic pyroxene and an abundant swarm of magnetite microlites which are chiefly noticeable on account of their number, seriously rivalling the felspar in quantity, and their tendency to aggregate in five- and six-rayed stars. Magnetite also occurs in pyritized clots which are usually devoid of crystal boundaries, and as there are no signs of reaction between iron ore and the groundmass, it must be ranked as an original accessory. Chlor-apatite in typical acicular crystals is an important accessory.

The above described rock type passes laterally into a vitreous selvage which apart from the dominance of glass portrays much the same features on a reduced scale. However, the labradorite laths are absent, and the only felspars are bytownitic phenocrysts. Here no re-solution effects are shown. The stellate tendency of the magnetite microlites is preserved, but their number is much reduced. The glass in this portion of the rock makes up about 80 per cent of the field.

Passing to the actual contact with the acid mass, the basic side is mostly glassy, with an occasional phenocryst of the calcic plagioclase. The magnetite here is best described as dust. More acid plagioclase is entirely absent. This glassy zone is palagonitized and in specimens from the plane of motion is granulitized for a small way inward.

Although mineralogically these basaltic rocks show a relationship with quartz-dolerite, in texture they are considerably finer than the quartz-dolerite contact with the Inferior Oolite sandstones. Between the acid body and this fine-grained basic one is a clean cut contact which, on the basic rock, shows quartzitic xenoliths clinging to it, and in some cases penetrating it. These xenoliths pass out into the acid rock and are to be seen in all stages of mechanical incorporation in the acid bodies—they show no reaction phenomena with either acid or basic rock. The xenoliths consist of quartz grains which may show fretted margins, but no signs of inversion from a higher temperature form and are strictly comparable with the hardened sandstone country rock.

With regard to the acid side of the contact, this is crowded with xenoliths which are broken up and penetrated by the invading acid magma and the crevices filled with cryptocrystalline material, together with a little brown mica and chlorite. Away from the contact the acid rock shows cleaved phenocrysts of a perthitic felspar, with pronounced carlsbad twinning as a feature, which have been subjected to auto-pneumatolytic processes, leaving them very much altered, but still retaining idiomorphic sections.

Apart from the xenolithic quartz the groundmass consists of small

alkali felspars, chiefly soda orthoclase, and quartz which shows a tendency to granophyric texture in some parts. In others the groundmass is definitely felsitic.

That this basalt represents the chilled margins of the quartz-dolerite that have undergone a secondary alteration in texture consequent upon the action of the acid magma seems reasonably certain from mineralogical and textural similarities together with the evidence of the quartz xenoliths.

Of interest is the basalt from the plane of motion which is connected with the intrusion of a cone sheet. The marginal modification of the basalt has been mentioned, and no further stress results are seen. The leucocratic part of the zone can only be described as a mélange. Portions of the acid rock are present showing cleaving and marginal granulitization of the perthitic felspar, together with the granulitization and straining of the quartz. Texture has been completely destroyed, and a linear tendency can be discerned. The amount of quartz is far in excess of that present in the normal acid rock, whilst a pale diopsidic pyroxene occurs in granules as also does a spongy colourless garnet. It would seem that in part this mélange has some Moinian sediments brought up from the Pre-Cambrian floor by the cone sheet.

(ii) The main quartz-dolerite has been described, and although it compares well with the original Talaidh type, it presents several features incompatible with a rock of uninterrupted magmatic descent. These features may be summarized as consisting of the albitization of felspar, the alteration of pyroxene, and the development of biotite. In thin sections cut from the merging margin these features are very much more in evidence, and the felspars have been more or less completely albitized whilst still retaining their characteristic shapes and stellate tendency. Soda-orthoclase is much more in evidence, pyroxene has been converted to chloritic pseudomorphs, abundant reddish biotite has arisen, and the pyroxene-magnetite association is very prominent. The mesostasis is also much more noticeable, and now carries fairly plentiful biotite and a little re-crystallized monoclinic pyroxene. Apatite is the principal accessory mineral occurring in characteristic long needles. Though it has been amply demonstrated that hybridization can produce normal rock types, the strewing about of coloured minerals regarded by Bowen (1928) as a characteristic of hybrids suggests that in this case processes other than the deuteric effect advocated by Fenner (1926) have been at work. It would serve no useful purpose to enumerate similar occurrences, but references may be had in a paper by Nockolds (1933).

As one passes into the more acid areas, the above characteristics become even more pronounced and sporadic occurrences of a diopsidic augite were noted in stout crystals, whilst the biotite was just as

prominent. When the most acid portions and the xenoliths are examined, it is seen that biotite is at its maximum in the siliceous and alkaline areas, pyroxene and iron ore are granular, plagioclase has more or less completely gone to albite, and granules of anti-perthite and anorthoclase together with phenocrysts of perthite begin to be common. Interspersed is plentiful quartz of primary and secondary origin. Notable, too, on the margins of the hybrid and the xenoliths is the development of vesicles carrying augite, plagioclase, or mica. This is significant in view of Harker's suggestion regarding the origin of similar vesicles associated with hybrid rocks in Skye (1904).

Petrology of the Acid Components

The acid body in the hand specimen shows a fine-grained white rock with large phenocrysts of perthitic felspar and a marginal pinkness due to weathering. It is fairly closely jointed, giving a serrated appearance to the outcrop.

Microscopic examination shows the phenocrysts to consist of a kaolinized perthite with a prominent carlsbad twinning. Their average size is about 2 mm. The groundmass is quartzo-felspathic, the felspar consisting of a mosaic of acid plagioclase of composition varying from albite to anorthoclase. Quartz, almost totally confined to the groundmass, sometimes occurs in bypyramidal phenocrysts which are much fractured and corroded. This quartzo-felspathic groundmass shows rapid variations from a mosaic to granophyric and felsitic textures. It is not desirable to name the rock on textural grounds for this reason, but the mineral content indicates strong bostonitic affinities and the term quartz-bostonite seems appropriate.

Coloured mineral content is low in the parts away from the quartz-dolerite, and consists of small flecks of reddish biotite together with occasional chlorite pseudomorphs after pyroxene, doubtless of xenolithic origin.

Accessories include pyritized magnetite in anhedral granules, apatite in short needles, and a very small content of zircon and spinel.

Altogether the term granophyre is a misnomer and is applicable rather to a texture, which is of sporadic occurrence, than to the petrographical nature of the rock. In general this bostonitic rock is reminiscent, to a certain degree, of the acid mesostasis of the quartz-dolerite.

Petrogenesis and Intrusion Mechanics

From the foregoing it is seen that although there is a range in chemical characters from basic to acid, there is no straightforward

differentiation relation between the members of the intrusion. The quartz-dolerite, even in its central portions, shows evidence of contamination, whilst the bostonitic component shows evidence of a like nature. In addition there are the undoubted modifications of both types along the merging contacts whilst the basic xenoliths demonstrate some stages in the processes of hybridization.

It is convenient then to adopt the terms of Tomkeieff and Marshall (1935) and distinguish " deep seated " and " contact " hybrids. To the former category belong the quartz-dolerite and bostonitic facies whilst the xenoliths and their aureoles of contamination belong to the latter. In addition there are certain deuteric effects in both bodies distinct, in the main, from contamination effects, though doubtless the agents responsible for the deuteric effects played an appropriate part in facilitating the course of hybridization. These effects are chiefly auto-pneumatolytic such as those affecting the mesostasis in the quartz-dolerite.

The course of the contact hybridization has been one of transfer of calcic material from the xenoliths to the acid material and the migration of alkali molecules to the basic material—a process demonstrated under the name of " reciprocal reaction " by Read (1924) with sedimentary xenoliths in a basic magma and by Thomas (1922) in connection with the sapphire-bearing dykes of Mull. The distribution of stable phases from xenolithic material in the acid rock was facilitated by this process of reactive solution coupled with its attendant process of mechanical disintegration until, in some regions, a mineralogically uniform basified quartz-bostonite was formed, only having tell-tale biotite and pyroxene to bear witness to the processes involved.

The course of formation of the contact hybrids is observable in all stages, and the course of the deep-seated hybridism must be pursued. Unfortunately the view set forward by Thomas (in Richey, Thomas, and others, 1930) that " as now encountered it (the quartz-dolerite) is modified to a great extent by acid material that has penetrated it in all directions from the subsequently intruded granophyre or bostonite " cannot be accepted as an explanation of the complete hybridism of an original Talaidh type quartz-dolerite, since the penetration referred to is either controlled by the primitive columnar structures or associated with contact brecciation. The results of interaction between such acid penetrations and quartz-dolerite are similar to those of the xenoliths, and only affect the basic rock marginally. Away from the margins some slight pneumatolytic effects are seen, but differ little from those effected by the mesostasis, indeed in some spots the mesostasis is segregated into veins which are very similar to the thinner acid penetrations.

Thus it is seen that " deep seated " hybridism must have played

some part in impressing aberrant features upon a Talaidh type dolerite.

Natural uninterrupted differentiates of the non-porphyritic central magma type such as was the parent of Talaidh quartz-dolerites are characterized by the concentration of alkalies in the acid pole. This is seen to some extent in the mesostasis, but on a large scale gives rise to craignurites and, in the limit, to soda granophyres. Whatever the original composition of the Sròn Bheag quartz-bostonite, it was not craignuritic when intruded. Apart from perthitic felspar all craignuritic characters are lacking. The partial granophyric texture confirms the assumption. Hence it is seen that the two major components have origins of debatable purity.

To explain these departures from the pure line, two magma-types, acid and basic, must be invoked. This, together with their co-existence, occasions no difficulty to petrogenetical thought which has long accepted the idea. These would, unless some intercrustal mixing and reaction took place, crystallize as pure soda-granophyre and Talaidh quartz-dolerite. At this point attention must be drawn to Nockolds's scheme of contrasted differentiation (1934) which states that " if, as we believe, the basic material in the magma reservoir solidifies, leaving a mobile acid residuum (here are the two magma types) then the basic intrusion represents a portion of the basic material at a time when some of it, at least, was still liquid. The acid residuum could not be intruded first for the simple reason that it was not there, and it is not until solidification of the basic material takes place that the acid residuum can be intruded as a distinct later injection."

Reaction of the basic solid with the acid residuum in depth would lead to the observed basifying of the acid magma with the formation of the quartz-bostonite.

If this is the case it is rather difficult to account for the observed anomalies in the quartz-dolerite which are not dependent upon auto-pneumatolysis or deuteric effects.

E. B. Bailey would doubtless apply the hypothesis that two complementary magmas froze in the reservoir and, naturally, did so in order of their densities. Remelting from the base upwards, through rise of the isogeotherms, would enable the basic fraction to rise through the more viscous acid fraction, mixing and reacting with it slightly, into the dyke fissure and followed in due time by the basified acid magma (Bailey and others, 1924). Such an explanation has, it is feared, many frailties but it does supply acidified doleritic magma and basified granophyric magma in the right order.

The authors of the Mull Memoir point out, however; that features characteristic of hybrids have been produced in a partially consolidated magma by the migration of its own acid differentiate. This implies

the existence of stresses which should destroy the subophitic texture to some degree. The quartz-dolerite does not show mechanical obliteration of texture except in the contact hybrid class, whilst it is felt that the general thesis of H. H. Thomas, that either an independent acid magma has reacted with the basic rock, or that co-existing magmas of widely differing compositions have commingled prior to, or during, their intrusion, is correct ; in view of the similarities of the mesostasis to the quartz-bostonite, it must be held that the hybridization of Sròn Bheag is of the deep seated nature, of which, in this case, the contact variety is only a visible demonstration of the stages involved. In general the contamination of the complementary magmas was only slight but quite sufficient to produce visible effects in the consolidated basic products where no reactive effects with either mesostasis or bostonitic penetrations can be seen. With regard to the quartz-bostonite away from the zone of contact effects, its contaminated nature is undoubted.

The method of intrusion raises some points of interest in that the sequence is acid—basic—acid in the spatial sense, though the time sequence is normal. Based chiefly upon Harker's work (1904) an impression has gained ground that the normal spatial sequence in composite dykes and sills is basic flanking acid, the acid body being intruded into the central parts of the basic body at a later date. Little or no explanation has been offered as to the mechanics determining such intrusions of abnormal spatial relations. It is significant that the time relations are almost invariably basic to acid, no matter what the field relations.

Gunn (1903) described a sill in southern Bute which appeared to depart from this time relationship, but subsequent examination by Harker (1909) did not confirm this. Further, Harker suspected that instead of being a triple component sill it was in reality quintuple. Smellie (1912–13) re-examined this sill and, whilst confirming Harker's suspicions, showed that the commonly accepted mechanics of intrusion did not hold in this instance, and was constrained to formulate an explanation that fitted the facts. This explanation in view of later works on so-called abnormal composite intrusions appears capable of wider application. Guppy and Hawkes (1925) arrive at much the same conclusion in the case of an Icelandic composite dyke. There would seem to be a limiting value as regards width above which the orthodox mechanics do not obtain in these bodies. In brief, Smellie's mechanics show that in thick dyke or sheet intrusions " it frequently happens that the fine grained margins about a foot wide adhere to the country rock firmly, while the massive centre assumes columnar joints and is separated from the margins by planes of weakness containing much shattered rock belonging neither to the columnar centre

nor to the margins ". The later acid magma would advance up these weak belts.

Application of the conception to Sròn Bheag requires little modification, and the intrusive acts leading to the spatial sequence observed become intelligible.

Summary and Conclusions

In the Sròn Bheag composite intrusion an abnormal spatial relation of acid—basic—acid is observed. The components consist of a central mass of quartz-dolerite and flanking bodies of quartz-bostonite.

A series of alteration effects can be observed :—

I. Deuteric effects leading to alteration of felspar and coloured minerals in acid and basic rocks. These are in part ascribable to auto-pneumatolysis and reaction with the basic fraction by the acid mesostasis where in contact with the basic fraction.

II. Contact hybridization which is discernible in all stages in the basic xenoliths, the merging portion of the contacts, and along the primitive columnar joints and marginal shatter belts that have been penetrated by the acid magma.

III. Deep seated hybridization which is discernible in those parts of the quartz-dolerite which are unaffected by the mesostasis. It takes the form of alkali-rich felspar unattended by alteration products of a more basic one, and also in the sodic borders of some of the more basic felspars, together with a small amount of primary quartz. The almost complete reaction of olivine and rhombic pyroxene precludes much free quartz arising from incomplete reaction at this stage. In the quartz-bostonite this type of hybridization is indicated in portions remote from the contact, and in xenoliths by the occurrence of mica in wisps and shreds, the prevalence of pyroxene and the textural tendency towards the granophyric as distinct from the craignuritic—which latter might be expected of a pure differentiate from the parent magma type.

It is concluded that the subterranean processes postulated by Bailey have operated in arriving at two magmas of contrasted composition with the necessity of some degree of commingling before intrusion, the nature of which was determined by the consideration laid down by Smellie.

The author's original aim was a comparative study of a number of British Tertiary composite intrusions, but the incidence of the war and his continued absence from the United Kingdom have necessitated the indefinite postponement of these plans. He feels, however, that it is worth putting on record the details of the Sròn Bheag intrusion, in order to emphasize the problems both of petrogenesis and of intrusion mechanism which it presents.

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A Remarkable Example of Superficial Folding due to Glacial Drag, near Aberystwyth

By John Challinor

(PLATE IV)

At a distance of about two and a half miles from Aberystwyth, the road leading eastwards towards Devil's Bridge curves round the north side of a small knoll on the ridge separating the larger valley of the Rheidol on the north from the smaller valley of the Paith on the south. The road here reaches a height of 400 feet and the knoll rises a further 100 feet above it. Opening directly from the south side of the road, a quarry (now disused) has been excavated in the knoll and in this quarry the Aberystwyth Grits present a very striking appearance, showing a zig-zag structure with one fold above the other.

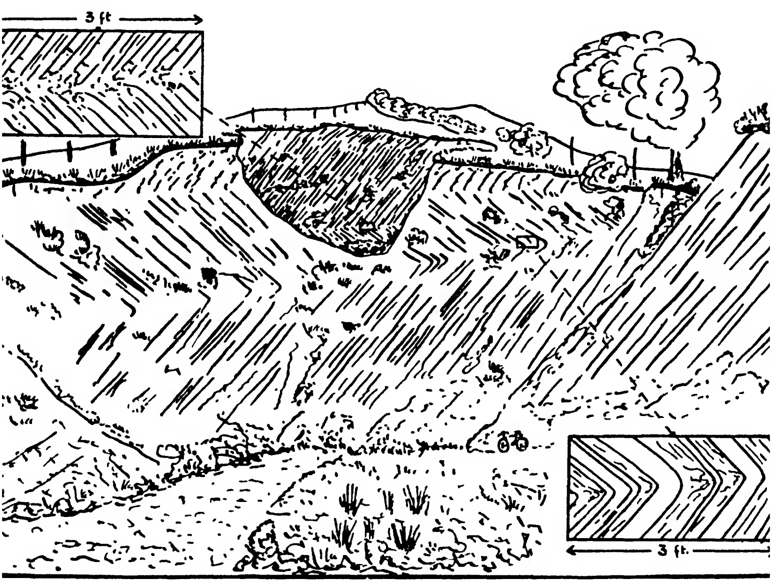
The lower fold is plainly visible on the face of the main part of the quarry, and is obviously one of the ordinary tectonic kind, but the nature of the upper fold is only apparent on a close inspection at the back of a smaller excavation above. All that is seen of this fold from the road or the floor of the quarry is that the uppermost limb (with an eastward dip) forms a compact mass, so that it would be allowable to assume that it was of a similar kind to the other. A hint, however, that this may not be so is given by the broken rock and subsoil near the top of the main quarry-face where this material is seen to be curved upwards and backwards (see Text-fig. 1 and Pl. IV, fig. 1).

An examination of the rocks of the uppermost limb in the small excavation shows that they are somewhat shattered along small joints, but the really significant fact here is that the whole mass is seen to have been torn apart from the rocks below so that the beds, particularly the harder (siltstone) beds, are left "gaping" along the "axis" of the fold. There has not been any general translatory movement. This condition seems to be readily explainable on the supposition that a mass of ice, moving westwards towards the sea from the North Cardiganshire highlands, passed over the protuberant knoll and bent back the strata which opposed their bedding to its motion.

There is a very marked contrast between the way in which the beds are broken along the upper "axis" and the way in which they pass with perfect continuity over the axis of the truly tectonic fold below (see the insets in Text-fig. 1 and Pl. IV, figs. 3 and 4). The less competent (mudstone) bands, also, show thickening, with some minor contortions, in the bent zone, while these characteristics of tectonic folding are absent in the fractured zone. At a little distance, however, as already stated, the zig-zag deformation appears to be all of one piece.

Some finely displayed shrinkage-crack " negatives " in relief, indicating under surfaces, show that the newer beds are to the west (right). That is to say, in the lowest part of the quarry the beds are overturned by tectonic folding while in the highest part they are overturned by glacial drag.

There is no definite glacial drift to be seen along the top edges of the quarry nor are there any exposures or indications of such deposits on or near the knoll. The shape of the knoll itself, as seen from across the Rheidol valley, may be partly due to ice-moulding as it looks rather like a large roche moutonnée (see Pl. IV, fig. 2).



TEXT-FIG. 1.—Generalized sketch of the " glacial drag " quarry near Aberystwyth, with critical parts of the structure shown inset, looking south along the strike of the beds and taken as if from a point above the roadway.

Probably the best known examples in Britain of " terminal curvature " due to glacial drag are those in Lancashire (Tiddeman, 1872, p. 480, and Jowett, 1914, pp. 209, 227, pl. xxxiii), and of these the clearest appears to be that at Rishton, near Blackburn. The exposure in the quarry at Rishton is not mentioned by Tiddeman or Jowett, but a photograph of it, taken in 1912 by J. Ranson, has been published by the Geologists' Association and a print has been incorporated in the second published series of British Association geological photographs

(Ranson, 1928, p. 175, pl. ii*a*, and Ranson, 1931). This photograph has been used to illustrate superficial curvature in recent geological text-books. In one of these it is given as an example of soil and rock creep under the heading " landslides " though from Ranson's descriptions there does not seem to be much doubt about the glacial origin of the curvature. In the present instance, the superficial folding could not possibly be mistaken for surface creep due to gravity.

From the scantiness of descriptions of actual occurrences it seems that this interesting " drag " effect of glacial action is rather rare. The spectacular example to be seen near Aberystwyth and briefly described in the present article may thus perhaps be worthy of record.

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EXPLANATION OF PLATE

FIG. 1.—View from the floor of the quarry.
FIG. 2.—Distant view from the N.N.E. showing the shape of the knoll.
FIG. 3.—Near view of the bent zone on the face of the main excavation.
FIG. 4.—Near view of the broken zone at the back of the upper excavation.

FIG 3

FIG 4

FIG 1

FIG 2

The Granites of South-West Jersey

By Frederick A. Henson

(PLATES V–VII)

Introduction

THE aim of this paper is to present a brief description of the field relations of the South-West Granite Complex in the Island of Jersey, as shown by recent field work, together with a short description of the granites themselves. The area to be described forms a dissected peneplain, probably of Pliocene age. The magnificent coastal sections from St. Aubin to La Carrière reveal the nature of the two granite intrusions, the first into Pre-Cambrian shales, which are found to the north and north-east of the area ; and the second a newer granite intrusion into the older one. Inland, the scenery is less spectacular, but the path from St. Aubin to Corbière, which follows the old railway track, contains many excellent exposures of granite and shales, together with granite-shale contacts in the valley west of St. Aubin. West of Pont Marquet it traverses open country with dune sand encroaching from St. Ouen's Bay.

The south-western corner of Jersey consists essentially of one main granite boss intruded into Pre-Cambrian shales ; this was later followed by a second granite intrusion which may have originally occupied the approximate centre of the first. The relations of this later granite to the older intrusion are shown in Text-fig. 1. Although the north-west area of the granite is mainly covered with dune sand it is surprisingly different from the north-east area between Pont Marquet and Noirmont Manor. Here some of the original shale roof of the intrusion remains, revealing below it a finer grained and lighter coloured rock due to contamination of the original magma by the overlying shales. The Rev. C. Noury distinguished this contaminated rock as " granulit " in his pioneer work on the geology of Jersey. The coastal section in Belcroute Bay shows the older granite with xenoliths of contaminated granite and this passes into contaminated granite 50 yards from the granite-shale contact.

Numerous fine-grained dolerite dykes traverse the whole area, their main direction being east to west ; in width they vary from a few inches up to 20 feet or more. Mica-lamprophyres are much less numerous, their general direction being north to south.

General Field Relations

The granite complex is mainly confined to the area south of a line from La Carrière to St. Aubin. It is difficult to estimate the size and

true nature of the original intrusion, since erosion has removed all evidence of the extent and character of the mass, except on its northern boundary. Here dune sand effectively masks almost half of the boundary.

Good exposures of the granites are to be found below high water level ; these may be more informative than the cliff sections at times and possess an additional advantage of frequently being more easily accessible.

I. Older Granite

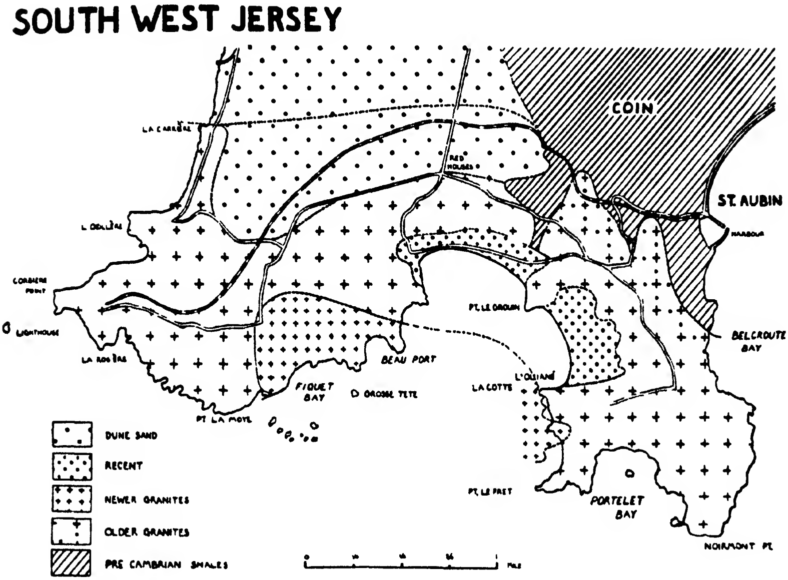
(*a*) *Contaminated Variety.*—In the rocks west of La Carrière and from Pont Marquet to Belcroute Bay the granite, at a varying distance of 50 to 100 yards from the granite-shale contact, is contaminated. The shales at this contact are only slightly metamorphosed. The coastal section from Noirmont Manor to Belcroute Bay shows the transition from the normal older granite, through varying degrees of contamination with xenoliths of contaminated granite in the normal type, to a wholly contaminated rock which extends from 50 yards south of the granite-shale contact. At the contact, which is quite distinct, the granite is a light coloured rock in which quartz, felspar, and decomposing dark minerals form the greater part ; locally it possesses a streaky appearance due to shale material which has not been completely assimilated.

The north-east boundary is much more informative than the north-west at La Carrière. At the former, part of the original shale roof over the intrusion remains, and in a roadside cutting at Mont Gras d'eau granitic veins, 9 inches thick, can be seen in the shales. In contrast the contaminated zone west of La Carrière is comparatively small and may well represent the contaminated wall, rather than the roof of the intrusion, as in the St. Aubin area.

(*b*) *Normal Granite.*—This coarsely crystalline rock, consisting of abundant quartz, felspar, and a smaller percentage of dark minerals forms the greater part of the complex. When fresh it is mottled pink and grey, but it weathers to a dull red colour with the decomposition of the felspar. In the advanced stage of weathering it shows quartz grains in bold relief (frequently showing a roughly parallel orientation in La Corbière area) in a dull red matrix. In one locality, near the old La Moye railway station, it is dug as gravel.

Xenoliths are not common ; where they do occur they are relatively small, being half to one inch in diameter ; they consist of altered shale material. In the quarry at La Rosière specimens showing biotite-rich bands were found. They provide evidence of alteration of xenoliths and indicate magmatic movement.

In coastal sections the granite forms magnificent scenery, the south-west coast being famous for its beauty. It exhibits characteristic block jointing and weathering. Inland good natural exposures are scarce. Field evidence, such as the lateral displacement of the dolerite dykes and newer granite-aplites, indicate that the granite has been subjected to considerable pressure from the south, either in the final stage of crystallization or immediately after its consolidation. Microscopic work confirms this view.



TEXT-FIG. 1.—Geological Map of South-West Jersey.

II. NEWER GRANITE

The intrusive form of this newer granite is shown in Text-fig. 1. Its shape is very roughly elliptical with the greatest area now remaining to be found in the west between Point La Moye and Beau Port. The eastern remnant forms the headland between La Cotte and Point Le Fret, and is small compared with the western part. The central part of the intrusion has been eroded away. At this point three important topographical features may be recognized. Firstly, the greater part of this newer granite intrusion has been removed by erosion, since it has been shattered to a greater degree than the older granite. Secondly, the general W.N.W.–E.S.E. trend of the eastern

part of St. Brelade's Bay follows the northern boundary of this later intrusion. Thirdly, as in the case of the older intrusion, the roof structure is revealed in the eastern area.

Three other small intrusions occur west of Point La Moye to La Corbière, they are not, however, indicated in Text-fig. 1.

In the field there is no difficulty in distinguishing the older from the newer granite. The older granite is coarsely crystalline whilst the newer is much finer grained with characteristic phenocrysts of quartz and some felspar up to 0·8 cm. in diameter, in a fine grained dull brown matrix in weathered material. Although there is an abrupt change in the lithological character of the granites at their contact, there is no topographical indication of this change.

The structure and jointing are very different from those in the older granite. Upon weathering this newer granite breaks into small brick-like blocks, the main direction of jointing being east to west. In fresher exposures the structure is more massive but shows marked tendencies to break in an east to west direction. The typical weathering and jointing are best shown at Beau Port, where castellated cliffs form a coastal scenery very distinct from that of La Corbière area. The sea stack south of La Cotte shows typical shattering effects.

Aplitic veins of the newer granite can be found throughout the entire mass of the older granite; in width they range from a few inches up to 10 or 15 feet. They are particularly numerous at La Corbière, La Rosière, and west of Portelet Bay. They invariably show lateral displacement varying from a few inches up to a foot or more, the displacement being to the north.

The most striking field relations of the two granites are to be seen in the coastal section from L'Ouainé to Point Le Fret. Here, in rocks exposed at low water, the older granite forms a roof over the newer and coastal erosion now reveals their relationship. As shown in Pl. VII, fig. 1, one effect of this later intrusion is the development of foliation in the older granite; in this case the newer granite is found within a foot of the foliated rock. The older rock has undergone only slight metamorphism and foliation occurs in a restricted area above the contact. It is probable that the older granite was in a plastic condition when the newer granite was intruded; since foliation is parallel to the surface of the later intrusion it may be attributed to compressional forces accompanying it.

Older and Newer Granite Contacts

The nature of the contact varies considerably and within comparatively short distances, the best exposures occurring in the cliff sections. In most cases the older granite appears to have suffered only slight and very local metamorphism. This is shown at the western

contact at the foot of the cliffs south-east of La Moye old Semaphore Station. Here the older granite possesses a definite porphyritic texture with phenocrysts of felspar, up to 2 cm. in length, in a darker ground mass. North of the Semaphore Station, where the granites are considerably weathered, there is no appreciable metamorphism and the boundary can be accurately mapped.

At Bouilly Port the boundary is indistinct ; a distance of 50 yards has to be traversed from north to south, before the older granite, veined with newer, gives way to the latter. In contrast the contact south of La Cotte is horizontal and very distinct. There is only very slight alteration of the older rock.

Pl. VII, fig. 2, illustrates the nature of the contact in a small intrusion west of Point La Moye, and shows the coarse texture and typical weathered surface of the older rock (above the pegmatite), in contrast to the relatively smooth surface of the later granite. The formation of a pegmatite is not usual ; in this case it is composed of quartz and felspar and varies from 4 to 6 inches in thickness.

Petrography

(*a*) *Older Granite.*—Megascopically, when fresh, the older granite is a mottled pale pink and grey rock of medium to coarse grain. Quartz is abundant, with grains up to 2 cm. in diameter ; numerous pale pink felspar crystals vary in length from 1·5 cm. to 2·5 cm., whilst shining plates and aggregates of biotite are disseminated throughout. On weathering the granite alters to a dull red colour in which only quartz, decomposing felspar, and biotite can be distinguished in a dull red matrix.

Microscopically the texture is hypidiomorphic and without orientation ; locally it may show almost a porphyritic texture. An average approximation of the main constituents is : quartz 40 per cent, perthite 25 per cent, biotite 15 per cent, plagioclase felspar 10 per cent, and other minerals, including fluorspar, hornblende, and accessories 10 per cent. The granite is comparatively poor in accessory minerals.

Main Constituents

Quartz.—Occurs in large and irregular grains frequently showing fractures and undulose extinction, the serrated edges of many grains forming a very characteristic feature. Inclusions are common and consist of perthite, plagioclase, chlorite, fluorspar, sericite, and magnetite. These numerous inclusions are apparently haphazard in their distribution.

Perthite.—This mineral, frequently showing good Carlsbad twinning, is developed in all sections of the older granite examined. Perthite occurs in two forms, both subhedral and anhedral. Inclusions of small

fragments of plagioclase, biotite, and quartz occasionally are found in the anhedral form. Antiperthite, although observed, is rare.

Plagioclase.—X′/(001) 6°–9° corresponding to oligoclase 24–28% An. Biaxial negative. The plagioclase felspar crystals occur in both euhedral and subhedral forms and exhibit zoned structures, polysynthetic albite and occasionally Carlsbad twinning. They contain few inclusions and show local alteration to sericite.

Biotite.—The most frequent occurrence of biotite is in aggregates of four to eight flakes and in association with plagioclase felspar, fluorspar, and other accessory minerals. It is a very deep brown in colour and pleochroic hales and inclusions are common. Deformation of biotite and alteration to chlorite and epidote frequently occur. Inclusions consist of apatite, zircon, rarely sphene, and allanite.

Fluorspar.—Shows considerable variation in amount and distribution ; it occurs in colourless crystals occasionally showing purple blotches. In a section from La Rosière the percentage of fluorspar is approximately 5 per cent.

Hornblende.—Few sections reveal more than an occasional hornblende crystal ; as in the case of biotite it is a very dark variety and is strongly pleochroic.

Accessories. These include : magnetite, ilmenite, apatite, chlorite, epidote, zircon, sphene, and allanite.

(*b*) *Newer Granite.*—Megascopically a fine-grained, mottled dull brown and grey rock containing rounded grains of quartz and phenocrysts of felspar. The diameter of the quartz grains may be as much as 0·8 cm. ; the felspar phenocrysts are smaller and less common. On weathered surfaces this characteristic texture is clearly seen. Here the quartz grains stand out from a dull brown surface which is pitted with remnants of former felspar crystals.

Microscopically the newer granite has a porphyritic texture, its constituent minerals are similar both in their relative proportions and characters to those of the older granite. There can be little doubt that both granites were derived from the same parent magma and that the later granite has probably been subjected to considerable pressure, due perhaps to orogenic forces at the time of its injection. Only a brief description of its constituent minerals will be given.

Quartz.—The larger rounded grains show serrated edges, fractures, and undulose extinction. They contain inclusions of perthite, plagioclase, biotite, and sericite. The smaller quartz grains also exhibit serrated edges and undulose extinction ; inclusions in the small grains are less numerous.

Perthite.—Abundant crystals showing good Carlsbad twinning are common, inclusions are few.

Plagioclase.—Zoned crystals showing albite and Carlsbad twinning

occur ; the composition is approximately the same as in the older granite with a tendency to be slightly more acid.

Biotite.—This mineral is considerably altered to chlorite and shows evidence of shearing. Inclusions are common and include apatite, magnetite, and zircon.

Other minerals include epidote, ilmenite, and fluorspar.

Conclusion

The two granites which form the south-west area of Jersey are very closely related mineralogically, and were presumably derived from the same parent magma ; the interval between the two intrusions was comparatively short. They were intruded into unfossiliferous Pre-Cambrian shales, and no other sedimentary series exist in the area ; consequently determination of the age of the complex presents many problems.

As the newer granite was intruded at a time of greater crustal deformation and stress than the older intrusion, its existence may well be due to the culmination of orogenic forces causing a recrudescence of magmatic injection within the area. The elliptical form of the intrusion with the major axis lying from east to west, and the characteristic east to west trend lines and structure, make it reasonable to assume that orogenic forces came from the south. From microscopic evidence, such as the deformation of biotite, the serrated edges and undulose extinction of quartz grains, further evidence is available of movement and compressional forces. The older granite also shows these effects but to a less degree. In the field the lateral displacement of dolerite dykes to the north, and to a lesser degree of aplitic veins of newer granite, confirms the view that pressure came from the south.

Summarizing, it appears that the older coarse grained granite was intruded under conditions of comparative quiet or only mild tectonic forces. The period of its crystallization, when compared with the newer granite was long, and during this period tectonic forces gradually increased. In the period between the granite intrusions the dolerite dykes were injected from a source to the east. The older granite, both at this stage and at that of the later injection, was in a plastic condition. The newer granite was probably intruded at a peak period of orogenic forces, and its period of crystallization was short. After its consolidation the whole complex, still in a plastic state, was subjected to decreasing pressure from the south. The age of the intrusion I tentatively propose as Armorican, the sequence being as follows :—

3 Newer Granite, } Early Permian or Late
2 Dolerite dykes. } Carboniferous.
1 Older Granite.

Finally I wish to express my thanks to Professor H. L. Hawkins, F.R.S., and Miss P. S. Walder, of the Geological Department of the University of Reading, for their encouragement and helpful criticism during the preparation of this paper. To Mr. R. A. Barker, Laboratory Attendant in the Geological Department of the University of Reading, I am greatly indebted for the preparation of photographs and photomicrographs. Mr. A. J. Robinson has been extremely helpful to me and I look forward to further field work with him.

EXPLANATION OF PLATES

Plate V

(1) Older Granite, Noirmont Point. X Nicols, × 20. Section shows characteristic texture of the older granite. The minerals include quartz, perthite showing Carlsbad twinning, biotite, chlorite, and fluorspar.

(2) Older Granite, L'Oeillère. Ordinary light, × 20. Minerals in the section are quartz, perthite, oligoclase, biotite with inclusions, chlorite, hornblende, fluorspar, and ilmenite.

Plate VI

(1) Older Granite, north-west corner of Portelet Bay. X Nicols, × 36. Section shows a zoned crystal of the cerium-bearing mineral allanite, in a chlorite pseudomorph of biotite in which it has produced a strong pleochroic halo. Oligoclase, showing albite twinning, biotite, and quartz also occur.

(2) Newer Granite, La Cotte. X Nicols, × 20. Section illustrates the characteristic texture of the newer granite in which both a large quartz grain and numerous small grains can be seen. Other minerals include perthite, plagioclase, and biotite.

Plate VII

(1) Foliation of Older Granite, 250 yds. north of Point Le Fret.

(2) Pegmatite at contact of Older and Newer Granites.

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1

× 20

2

× 20

PHOTOMICROGRAPHS OF JERSEY GRANITES.

1

× 36

2

× 20

PHOTOMICROGRAPHS OF JERSEY GRANITES.

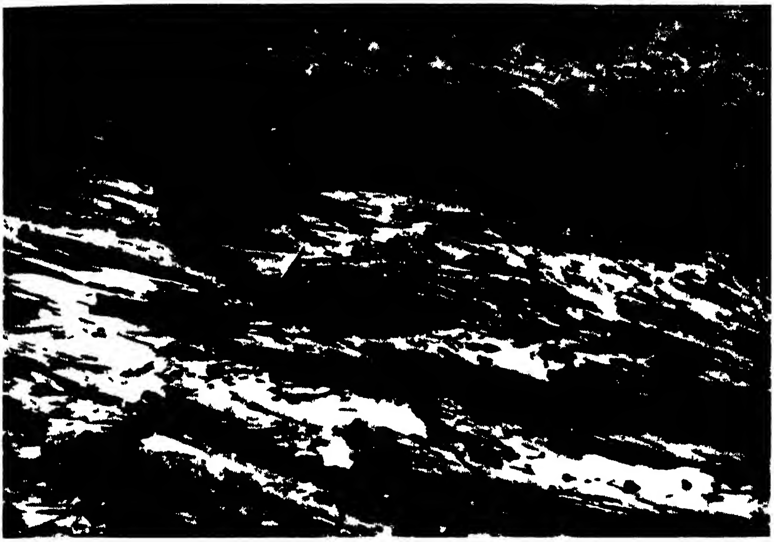

FIG. 1.—Foliation of Older Granite, 250 yards north of Point Le Fret.

FIG. 2.—Pegmatite at contact of Older and Newer Granites.

Facies Change and Lithological Variation in the Permocarboniferous Formation of North-West Pahang and South-West Kelantan, Malaya

By J. A. RICHARDSON (Geologist, Malayan Geological Survey, 1937–1946)

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FACIES change and lithological variation traceable in the outcrop of the Permocarboniferous rocks exposed over portions of some 1,400 square miles of jungle country in north-west Pahang and south-west Kelantan are outlined in this paper. The area, some 70 miles N.–S. and 10 to 25 miles E.–W., is bounded by the 101° 45′ E. meridian in the west and by the Gunong Tahan and Gunong Benom Ranges in the east (Text-fig. 1A). The territory described lies mostly in Ulu Pahang of which a reconnaissance map, scale 8 miles to an inch, and a memoir have been published by Scrivenor (1911). Between 1937 and 1941 the 1,200 square miles lying between meridians 101° 45′ E. and 102° 00′ E. have been mapped partly on the scale of 1½ inches and partly 2 inches to a mile. The geology of the southernmost 300 square miles (Sheet 3 B/4, Raub) has been described by Willbourn (A.R., 1933–34) and the writer (1939); interim reports on the 300 miles (Sheets 2 N/16, Benta, and 2 O/13, Lipis) immediately north have been published by Service (A.R., 1938–1940), and of the northern 600 square miles (Sheets 2 N/12, Chegar Perah, and 2 N/8, Merapoh) by the writer (A.R., 1937–1940; 1946).

The Arenaceous Formation of the Main Range Foothills in the west, the Triassic rocks of the Gunong Tahan Range and the granites and hybrid rocks of the Gunong Benom Range in the east, form a frame within which the Permocarboniferous rocks are enclosed. Several important igneous intrusions interrupt the continuity of their outcrop.

Broadly speaking, the Permocarboniferous Formation in western Malaya is a monotonous series of limestones or shales, or of both types together. In Perak, Savage (1937) has mapped "Limestone with no interbedded schist" and "Limestone with interbedded schist" in the Sungei Siput District (Sheet 2 N/1), and Ingham (1938) has distinguished a "Calcareous Facies" and an "Argillaceous Facies" in the Tapah and Telok Anson Districts (Sheets 2 N/13 and 2 N/14).

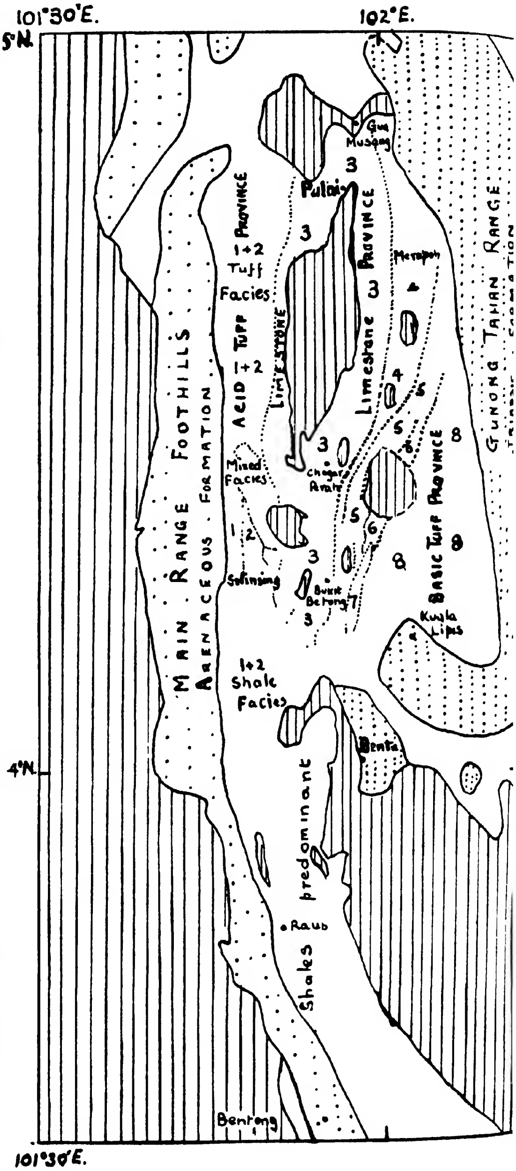
In Malaya east of the Main Range lithological variety has been introduced by important developments of the Pahang Volcanic Series conformably interbedded with Permocarboniferous limestones and

shales. Moreover, facies change and lithological variation occur more frequently and over shorter distances of outcrop than is usual in western Malaya. Conditions of deposition were clearly unstable in eastern Malaya and this part of the Malayan basin of sedimentation lay partly within the zone of sub-littoral variables. A shoreline of the Permocarboniferous geosyncline lay north and north-east of the parts of Pahang and Kelantan herein described, and the sea deepened towards south and south-west (1931; 1946).

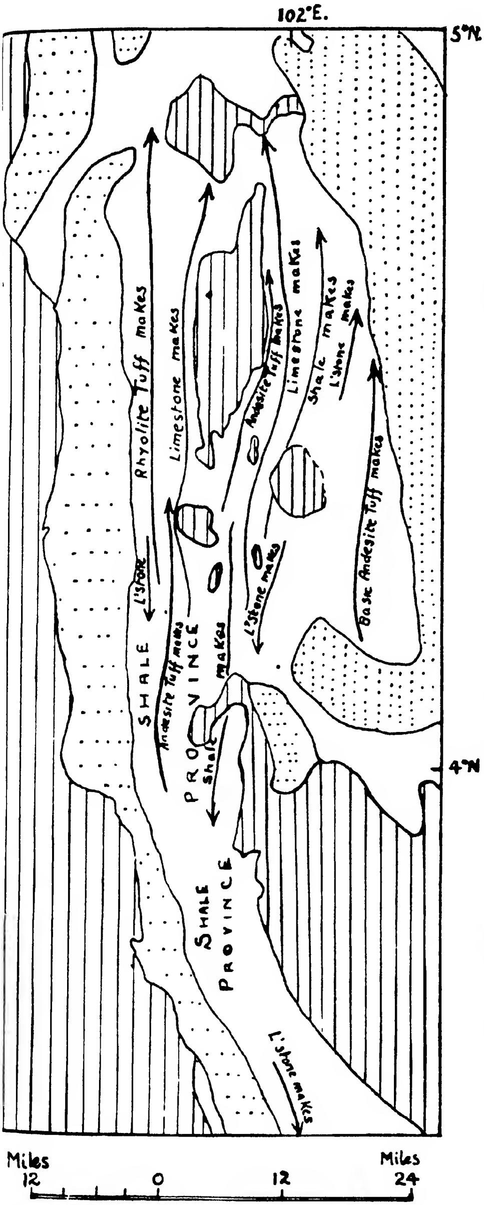
The Permocarboniferous rocks of north-west Pahang and south-west Kelantan belong to three major facies and two sub-facies, viz. :—

1. Calcareous Facies: Limestones preponderant.
   1*a*. Mixed Limestone and Shale Sub-facies.
2. Argillaceous Facies: Shales (and phyllites) predominant.
   2*a*. Mixed Shale and Rhyolite Tuff Sub-facies.
3. Volcanic Facies (Pahang Volcanic Series): Pyroclastic rocks (tuffs) predominant.

1. *Calcareous Facies*.—Massively bedded and strongly jointed limestone and, rarely, almost pure dolomite rock.



TEXT-FIG. 1A.—Geological sketch-map of North-West Pahang, Malaya, showing distribution of the Permocarboniferous Formation (plain) and of its lithological subdivisions (1–8). Igneous rocks are hachured vertically.



TEXT-FIG. 1B.—The major facies changes in the Permocarboniferous Formation of North-West Pahang, Malaya.

(*a*) White: containing small percentages of terrigenous material.
(*b*) Grey: argillaceous and slightly carbonaceous.
(*c*) Black: containing as much as 3 per cent carbon dust in addition to argillaceous and pyroclastic residues.

The limestones are hard and compact, non-porous, brittle, and splintery. The MgO percentage is variable; usually it is less than 5 per cent but occasionally approximates to that of pure dolomite rock (*circa* 22 per cent). The limestones contain usually not more than some 5 per cent (sometimes nearly 10 per cent) of insoluble residues, clay minerals, volcanic dust, fragments of quartz, orthoclase, albite, albite-oligoclase, and about fifteen species of common heavy minerals including zircon, tourmaline, black iron ores, epidote, chlorite, and limonite pellets.

Thin bands of shale, carbonaceous chert, and fine-grained quartzite composed of angular fragments set in a limonitic clay base, are interbedded with the limestones in some localities. They represent large-scale incursions of terrigenous material into the depositional areas.

1*a*. *The Mixed Limestone and Shale Sub-facies.*—Bands of limestone generally less than 3 inches thick separated by seams of shale. This group is confined to what appears to be the basal portion of the Permocarboniferous around

the Selensing Gold Mine and in the Serau and Satak valleys. It reflects periodic instability in depositional conditions. Locally, thicker limestone bands occur.

2. *Argillaceous Facies.*—The argillites (shales generally somewhat altered to phyllitic varieties, or to phyllites proper) may be either calcareous, carbonaceous, or both. They are usually more prevalent than limestones. Locally, lenticular bands of limestone and pyroclastic rocks and a few beds of chert are interstratified with the shales.

2*a*. *The Mixed Shale and Rhyolite Tuff Sub-facies.*—Bands of pale grey, fine-grained rhyolite tuff interlaminated with darker grey shale, some of it carbonaceous. Individual bands seldom exceed 2 inches in thickness ; commonly they are less than an inch. As a result the rock is strongly colour-banded, light and dark grey, and displays pronounced textural banding. This sub-facies is confined to the Satak and Serau valleys between the Bukit Ranjut syenite intrusion and Kuala Ingsor.

3. *The Volcanic Facies.*—Rhyolite tuffs, fine to medium grained, grey and well bedded, are preponderant in the basal divisions of the Permocarboniferous. Andesite-rhyolite tuffs of coarser grain and generally somewhat chloritic appear in the middle divisions ; coarse grained, highly chloritic andesite tuffs, agglomerates, and breccias occur a little higher in the succession and more basic tuffs containing some basalt attain a thick development at the top.

All these Permocarboniferous rocks are neritic with the probable exception of some of the coarser agglomerates and volcanic breccias which may in part be littoral. Intermittent vulcanicity was prevalent during the period.

In 1940, Service (Sheets 2 N/16 and 2 O/13) and the writer (Sheets 2 N/12 and 2 N/8) agreed upon a provisional lithological subdivision of the Permocarboniferous Formation in that part of its outcrop lying between Benta in the south and Pulai in the north (Table 1 and Text-fig. 1A).

No fossils of homotaxial value have yet been found in the Permocarboniferous rocks of this tract and thus the exact age-relationsnips of the several subdivisions cannot be stated. It is unknown, for example, whether or not disconformities or non-sequences occur. Similarly, although strike-faulting may be prevalent, its presence cannot readily be proved without the aid of fossils in a series so lithologically variable. The strata have been strongly folded and they dip generally eastwards at steep angles. The Triassic follows on in the east. The subdivisions shown in Table 1 are thus listed in approximately the correct order. The possibility of their having been duplicated by folding or faulting, or perhaps overturned has been touched upon by the writer (1946) but has not yet been either proved or disproved.

The main scheme of facies change and lithological variation, however, is traceable through some 70 miles of outcrop. The lithological subdivisions in Table 1 apply strictly only to the area of Sheets 2 N/8 and 2 N/12. South of the 4° 15′ N. parallel (Service's area) they change rapidly and tend towards the usual alternations of shales and

TABLE 1.—Provisional lithological subdivision of the Permocarboniferous Formation in N.W. Pahang and S.W. Kelantan (after H. Service and J. A. Richardson ; unpublished records).

Group			Lithological Description
Triassic			Quartzites, conglomerates, and shales of the G. Tahan Range.
PERMOCARBONIFEROUS	UPPER	8 (East)	Chloritic andesite tuffs and agglomerates of the Kechau and Ulu Tanum valleys.
		7	Upper limestone of the Tui valley.
		6	Chloritic rhyolite-andesite agglomerate and tuff with shale.
		5	Massively bedded mudstones and siltstones of the Tanum valley.
	MIDDLE	4	Chloritic rhyolite-andesite agglomerates, breccias, and tuffs with shales and some thin limestones.
		3	Middle limestones with some shales, tuffs, and agglomerates.
	LOWER	2	Mixed shale and rhyolite tuff sub-facies of the Serau valley.
		1 (West)	Shales, some tuffs and the mixed limestone and shale sub-facies.
			(*N.B.*—Groups 1 and 2 pass into a thick rhyolite tuff series north of Kuala Ingsor.)
?			Arenaceous Formation of the Main Range Foothills.

limestones together with relatively unimportant lenses of Pahang Volcanic Series rocks except along the eastern flank where the uppermost shales and basic pyroclasts remain strongly developed. Around Raub (Sheet 3 B/4 ; 1939) the Permocarboniferous consists largely of shale and phyllite with only two limestone areas and a few thin bands of andesite-rhyolite tuff corresponding to Groups 2 and 3 of Table 1. Still farther south around Bentong (Alexander's area, Sheet 3 B/8 ; A.R., 1938–1940) limestone again becomes more abundant.

Sedimentation began in Lower Permocarboniferous times with the accumulation of shales and a few thin bands of limestone in the south, and in Service's area, limestones became rather more prevalent. Pyroclastic material, however, was being introduced in considerable quantities almost simultaneously from a centre in the north and tongues of tuff spread out southwards into the shale province. About midway, conditions were favourable for the formation of the characteristic interlaminated shale and rhyolite tuff sub-facies which has, so far, been located nowhere else in Malaya. Superficially, these banded rocks resemble varved sediments. Colour-banding of shale around Raub caused by the interlamination of volcanic dust has been described by Scrivenor (1911, 1931) and the writer (1939). It represents the feathering out into the shale zone of fine volcanic dust from this same northern centre.

The Basal Groups (1 and 2) consist, therefore, of shales in the south, with limestones making southwards, and rhyolite tuffs and ashes with an outcrop width of some seven miles in the north extending through south-west and west Kelantan.

The succeeding Group 3 by contrast, contains one of the largest developments of limestone in Malaya. Here, the limestones die out rapidly south of the Sungei Jelai valley but make strongly northwards into southern Kelantan where they become very important around Gua Musang and Pulai. Shales on the whole are subordinate. The pyroclastic rocks present are of different composition from those of the older group. They comprise coarser grained, more basic andesite-rhyolite tuffs passing upwards into still coarser types in which andesite gradually becomes the preponderant rock constituent. During this period vulcanicity remained essentially explosive but the composition of the ejectamenta became increasingly more basic. Evidently a volcanic focus yielding andesite waxed in importance whilst the older rhyolitic centre waned *pari passu*. This belt of andesitic material likewise extends northwards into Kelantan. At the same time there was a falling off in the yield of mud and clay to the depositional basin with the result that Group 3 consists largely of limestones and rhyolite-andesite tuffs with relatively few shales.

The succeeding subdivision 4 comprises coarse tuffs, agglomerates, and breccias, in which the fragments may exceed a foot across, interbedded with shales and limestones. Angular slabs of more or less altered shale, phyllite, and limestone wall-rock in the pyroclasts point to their having been formed locally ; volcanic vents must have been sited in the vicinity probably off-shore in shallow water or fringing the old coastline. Similar rocks also occur in Kelantan, but they die out rapidly south of the Jelai valley.

This phase of explosive vulcanicity was succeeded by a period (5)

of quiescence during which rather structureless mudstones and siltstone were accumulated along the Tanum valley. Farther north in Ulu Tanum, the argillites pass into the limestones of the Cherual Range.

Vulcanicity (6) producing fragmental material at least as basic as that formed in the Middle Groups broke out again following the deposition of the argillites and, with a relatively short break during which massive dolomitic limestones (7) were laid down in the Tui valley, it continued almost until Triassic times. This Upper Permocarboniferous phase of volcanic activity (8) was one of the most important in Malaya ; andesite with some basaltic material was produced almost exclusively of more acid types. The volcanic loci lay extended approximately north and south through north-west Pahang and parts of southern Kelantan but their exact locations have not been determined. Dolerite dykes found in some places may have been connected with old andesitic volcanoes.

Text-fig. 1B shows schematically the sedimentational variation and the facies changes which occurred during the Permocarboniferous period in north-west Pahang and south-west Kelantan.

1. A coastline of the Malayan geosyncline lay north and north-east of the area described, and neritic sediments were accumulated in the basin throughout Permocarboniferous times.

2. Important centres of vulcanicity were sited probably in south-west and central Kelantan and in north-west Pahang near, or actually upon the old north or north-east coastline of this geosyncline.

3. Their products were overwhelmingly explosive and they changed in composition from acid in the beginning to basic at the close of the period. In early Permocarboniferous times the centres yielded rhyolitic material almost exclusively ; towards its middle stages they gave mixed rhyolitic and andesitic products, and in Upper Permocarboniferous times, andesitic and some basaltic ejectamenta.

4. In each group, the volcanic material, most abundant in the north, dies out southwards into the shale province.

5. Limestone was more abundantly formed in the south than in the north during Lower Permocarboniferous times. During the succeeding Middle and Upper periods, however, its main province lay farther northwards and there its maximum thicknesses were attained.

6. Concomitantly, the southern area remained permanently a shale province. Relatively small amounts of volcanic material drifted into it and a few rather unimportant limestones were laid down, presumably during phases either of clearer (perhaps deeper) water, or at times when the supply of mud and silt temporarily diminished.

7. At intervals, thin beds of fine-grained quartzite were deposited

interbedded with the limestone and shale, and carbonaceous chert was also formed amongst the shallow-water rocks.

The writer thanks Mr. E. S. Willbourn and Mr. J. B. Scrivenor who have read and commented upon the paper.

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Gala-Tarannon Beds in the Pentland Hills, near Edinburgh.

By ARCHIE LAMONT, Grant Institute of Geology, University of Edinburgh.

(*continued from p. 208*)

(*m*) *Annelida*

Robert Etheridge, Jnr. (1874A, p. 310), records that the same species of *Spirorbis* as that in the Lesmahgow Silurian occurs in the North Esk section. The D. J. Brown collection with the specimens referred to is missing at the Royal Scottish Museum ; but it would be interesting to know how closely these specimens compare with *S. lewisii* J. de C. Sowerby from the English Wenlock and Ludlow.

(*n*) *Trilobita*

Dr. C. J. Stubblefield (1939, pp. 66–7) in a discussion of possible migration and " colonies " writes as follows :—

> " In the Pentland Hills, the Wenlock [*sic*] trilobite fauna is richer than in the North English region ; Encrinurids, *Phacops*, Acastids, Cheirurids, and Odontopleurids are recorded (Peach and Horne, 1899, pp. 710–711), and a somewhat similar fauna is known from Girvan, but these northern faunas show few immigrated elements and could probably have been developed from the Girvan Llandovery faunas."

In other words, the Pentland Hills yield trilobites more obviously related to those of the Girvan Llandovery and Gala strata than to those of the Wenlock shales and limestone. The Woolhope Limestone below the Wenlock Shales in the West Midlands of England also seems to have a different fauna, so that we must go down into the Gala-Tarannon Series to obtain correlation of the Pentland Hills beds. At the same time the Pentland trilobites mostly show differences from those of the well known English and Welsh Upper Llandovery, nor are they the same as those of the Penkill Group at Girvan, which are now regarded (*vide supra*) as paulo-post-Upper Llandovery.

Comparisons with species in the Melbournian beds at South Yarra, Victoria, Australia, which some authors have ascribed to Llandovery and others to Middle Silurian (Gregory, 1900, p. 181), also may suggest that the Pentland neritic fauna lies somewhere between Upper Llandovery and Wenlock.

This is confirmed by two new species of trilobites recently collected. One is related to, but not the same as, Whittard's *Warburgella binodosa* from the Upper Llandovery of Shropshire (1938, pp. 97–8, pl. iii, fig. 4). The other is *Eoharpes domina* sp. nov., which has a fringe

approximately similar to that described and figured by Cowper Reed (1903, pp. 9–10, pl. ii, fig. 14), from Bargany Pond Burn in beds a little younger than the fossiliferous impure limestone in Penwhapple Gorge near Penkill. A near relative is *E. ottawaensis* var. *anticostiensis* Twenhofel, from the Upper Ordovician. It may be added that *E. domina* has proportions—except for a longer glabella—very like those of *H. consuetus* Billings (Twenhofel, 1927, p. 321, pl. liv, fig. 8) from the Chicotte formation of Anticosti Island. Like the Pentlands beds, the Chicotte formation has a relatively impoverished fauna as compared with the Jupiter formation (= partly Upper Llandovery) immediately below it. It is worth noting that earlier geologists like F. H. McLearn (1924, p. 26) put the Chicotte as high as Ludlow, while Twenhofel (1927, not 1909) brings it down to Wenlock, because its corals are close to or the same as Wenlock examples. In any case, the question may be raised as to whether the shelly faunas of the Southern Uplands of Scotland end at about the same stratigraphical level as do those of Anticosti Island.

Unfortunately the fine collection of twenty specimens of *Acidaspis* made by John Henderson is missing from the Royal Scottish Museum, but one specimen from the Bavelaw inlier in the Geological Survey collection, though labelled *Acidaspis brightii* Murchison, is evidently closer to *A. erinaceus* Marr and Nicholson from the Skelgill Beds, as the ridges at the sides of the glabella extend into lobes which lie further back than the posterior lobes of the glabella.

The commonest *Encrinurus* seems to come nearest to *E. onniensis* Whittard, but to differ persistently in the number of axial rings in the pygidium, which are fewer, and in the shorter mucro. Other specimens have been labelled *E.* cf. *shelvensis* Whittard, and it is interesting that the Shropshire pygidium referred to *E.* sp. compares in the steady tapering of the axis with that figured by Haswell (1865, pl. iv, fig. 4) in his drawing of *E. expansa* which has other features in common with *E. shelvensis.*

A large *Eophacops* is very common at Wetherlaw Linn. It has more than six facets per radius in the eye, which rules out *E. elliptifrons* (Esmark) the Llandovery species, and suggests one of the Wenlock forms. The rather long pygidium with numerous axial segments, however, points to comparison with *E. elliptifrons* var. *glaber* Marr and Nicholson, from Upper Birkhill beds in the Lake District.

Calymene blumenbachii (Brongniart) has not been seen from the Pentlands by the present writer, but there is a species of *Proetus* with lobed glabella which may have been mistaken for it. This bears some resemblance to *P. bowningensis* Mitchell from New South Wales. Other fragments, recently noticed at the Deerhope, suggest *C.* aff. *replicata* Shirley.

(*o*) *Ostracoda*

Apart from *Beyrichia kloedeni* McCoy the ostracods of the Pentlands appear to be mainly distinctive forms, and justify the separation of the fossiliferous beds from the Upper Llandovery below and the Wenlock above.

Entomis tuberosa Jones is not the same as *E. pelagica* Barrande from Stage Ff2, though T. R. Jones himself (1884, p. 393) suggests the comparison. Again *E. angelini* Jones, probably from Gotland, is shorter than *E. tuberosa*. *E. haswelliana* Jones and *E. globulosa* Jones, from the Pentlands, are distinguished from *E. reniformis* (Kolmodin), recorded from the Lower Ludlow of Sedgley, by having a more pronounced tubercle in the sulcus. *E. globulosa* occurs at Blair Farm, in the Girvan district, in what have been taken as lowest Wenlock beds. The same locality is reported to yield the Pentland species *E. impendens* Haswell (Peach and Horne, 1899, p. 549), which is also not very different from *E. reniformis*. In a table (p. 710) Peach and Horne record *E. impendens* from the Hagshaw inlier of the Lesmahagow area. It is to be regretted that in the text about that anticline (pp. 581–6) they do not mention whether it is from their alleged " Wenlock-Ludlow " or " Downtonian ". Some of the species, like *Orthis polygramma*, which they do list from the " Wenlock-Ludlow " suggest that it is neither of these formations which is present, but a Gala-Tarannon correlative of the Pentland Hills strata.

In *Bolbozoe scotica* Jones the anterior bulge, or tubercle, is not so large as in *B. bohemica* Barrande, from Stage Ee2. *B. divisa* Jones (olim *Entomidella*), apparently from Lower and Upper Ludlow, also differs from the Pentlands species in that it has a crescentic sulcus completely crossing the valve.

Cyprosis haswelli Jones is a unique form. It and some of the foregoing Ostracoda are omitted in Peach and Horne's list (1899, p. 710), though they do include *Cythere umbilicata* Jones and Holl, of which the type is from the Aymestry Limestone of Chances Pitch, Malvern, and which has also been recorded by its authors from Wenlock strata (1865, 1886B), but apparently not from the Pentlands. Peach may have been relying on a list compiled by Lapworth (1872, p. 174), in which the discrimination between Lower and Upper Pentland species is somewhat arbitrary, or he may have depended on an unverified record by Henderson (1874A, p. 374).

(*p*) *Phyllocarida*

Leif Størmer (1935) like most writers treats the Gala-Tarannon of the Pentland Hills as " Wenlockian ". He attaches importance to the occurrence of the Phyllocarid *Dictyocaris ramsayi* Salter, in great

numbers, along with occasional *D. slimoni* Salter and *D. salteri* Størmer. In the " Downtonian " at Stonehaven and Lesmahagow, though *D. ramsayi* is reported, the predominant species is *D. slimoni*. This is an important stratigraphical distinction, but the continuity of faunas is an indication of the Silurian age of the Scottish " Downtonian ". A possible specimen of abdominal segments of *Dictyocaris*, terminating in five or six caudal spines has been found in the Royal Scottish Museum, pointing to relationship with *Hymenocaris*. Fragments of *Ceratiocaris* are present in the Gutterford Burn and North Esk. From the latter comes a fine caudal spine of *C.* aff. *valida* T. R. Jones and H. Woodward.

(*q*) *Arachnida*

It is not proposed on this occasion to deal exhaustively with the affinities of the Eurypterida of the Pentlands, especially as a good deal of important type material at the Royal Scottish Museum is still missing. It may be said at once that though they are typical inhabitants of a sand and silt environment—as opposed to a limestone one—they have nothing to do with the Ludlow formation. In sand and silt, members of the family Stylonuridae tend to be abundant. In limestones, like the Kokomo and Bertie in North America and the Oesel beds in Estonia, the Eurypteridae predominate. Nevertheless there are significant comparisons between Pentland species and those from the Kokomo waterlime and the Guelph dolomite, as well as with forms from the Pittsford Shale and Shawangunk Grit. The correlation of some of these formations is not quite certain in terms of Gala-Tarannon and Wenlock, but so far as the U.S.A. are concerned they are all of pre-Bertie waterlime age. The Shawangunk Grit, which has been specially studied by Bradford Willard (1928, pp. 255–8), is assigned by him to the Lower Silurian. The present author is inclined to think that since the American formations are post-Upper Llandovery and post-Middle Clinton, they may include beds of Gala-Tarannon age.

Important records of fragments of " *Pterygotus* " in the Abbotsford Flags and Buckholm Sandstone of the Galashiels area (Lapworth, 1870, p. 52) indicate a related fauna in the Gala of the type area, but as the specimens have not been traced reference here is simply to the Pentlandian species.

Hughmilleria conica (Laurie) has important primitive features. The prosoma is more semi-circular than in other *Hughmilleriae*, including the American Ordovician *H. magna* Clarke and Ruedemann, from which *H. conica* also differs in the steady reduction in breadth of the mesosomatic segments from in front backwards. In all other forms the mesosoma of the adult is clearly widest at about its fourth segment. The semi-circular prosoma and the large eyes would indicate

that *H. conica* is more primitive than later Silurian forms like *H. norvegica* Kjaer, and also probably older than Pittsford Shales specimens of *H. socialis* Sarle.

The syntypes of *Slimonia* (?) *dubia* Laurie are two fragments—one 94 mm. long (including metasoma = 38 mm. and telson = 30 mm.), and the other 64 mm. (including rectangular prosoma = 19 mm.). The telson " more elongated . . . than in *S. acuminata* (Salter), and the broadest part . . . not so far back " (Laurie, 1899, p. 578), though probably belonging to an early type of *Slimonia*, is not very unlike that of *Hughmilleria socialis* Sarle (Clarke and Ruedemann, 1912, pl. 63, figs. 13, 15). One may also compare the anteriorly tapered telson referred to *H. shawangunk* (ibid., pl. 66, fig. 14), although it may represent a variety of that species. Laurie (1899, p. 579) says that a telson indistinguishable from that of *S. acuminata* has been found in the North Esk section. This probably refers to a find by John Henderson just below the red beds of the alleged " Downtonian " (Henderson, 1866, p. 18). Should this be verified, as seems likely, it will imply correlation with part of the Lesmahagow Silurian.

The large eyes of *Stylonurus macrophthalmus* Laurie may be regarded as a surviving " larval " feature and so may the " shovelling " border which runs about half way round the front of the prosoma. The horseshoe shape of the prosoma, though not in itself a primitive bio-character, is paralleled in the Schenectady shale (Ordovician) *S.* (?) *limbatus* Clarke and Ruedemann. The migration of the eyes towards the median line of the prosoma is also seen in a form as early as *S. modestus* Clarke and Ruedemann from the Normanskill shale (Ordovician). *S. macrophthalmus* possesses a significantly early feature in its short anterior walking appendages.

The transverse shape of the prosoma, with marked border round the front and sides, as well as the large eyes, leads one to compare *Stylonurus cyclophthalmus* Laurie with as early a form as *S. modestus.* There may also be a comparison with young stages of *Eurypterus maria* Clarke (cf. Clarke and Ruedemann, 1912, pl. 21, fig. 8, with Laurie, 1893B, pl. iii, fig. 15), but in *E. maria* the expansion of the mesosoma may have been in a vertical direction. Transverse prosoma, border, and large eyes are also found in *S.* (*Tarsopterus* ?) *myops* Clarke from the Shawangunk Grit, with which a small undescribed Pentlandian specimèn can be compared.

In *Stylonurus ornatus* Laurie, the prosoma is as long as wide, but the posterior margin is only three-fifths of the greatest width which is at one-third of the length from the anterior margin. There is a flattened border which diminishes at the sides ; and the eyes, which are about one-eighth of the length, lie well within the front and lateral margins. They are relatively smaller than in *S. macrophthalmus* and

S. cyclophthalmus. Other advanced features are the highly differentiated ornament of semi-circular sculpture and pits and the great lengthening of Appendages V and VI. The second, third, and fifth joints of Appendage VI are specially extended in form, in keeping with the great instability in the development of this " limb " in the Eurypterida generally. The epimera, however, are not so extremely developed in *S. ornatus* as in *S. macrophthalmus*. *S. ornatus* differs from later forms like *S. logani* Woodward and *S. powriei* Page in the greater length of the lateral appendages. There is a comparison between the keeled joints of appendages supposed to be those of *S. powriei*, found in the Silurian of Lesmahagow (Woodward, pl. xxi, fig. 2), and Laurie's figure (1893B, pl. i, fig. 6). In *S. logani* from Lesmahagow the prosoma is more quadrate, but the spines on the shorter appendages are not unlike those in *S. ornatus*, so far as these are known. A telson larger than that figured by Laurie shows ornament of fine, oblique lines.

Stylonurus (*Ctenopterus*) *elegans* Laurie compares with *S. cestrotus* (Clarke), from the Shawangunk Grit, in the denticulate margin of the prosoma, but shows what may be a more primitive feature in having spines of unequal lengths on Appendages III and IV. This latter character suggests *S. multispinosus* Clarke and Ruedemann from the Pittsford Shale.

Laurie (1899, p. 584) remarks that his species *Drepanopterus bembycioides* appears to be " the most primitive Eurypterid known ". It has a broad prosoma twice as wide as long, with broad " shovelling " margin inside which lie the eyes. There are four pairs of locomotory appendages, all of short tubular joints, showing no extension of the posterior pair. The metastoma is oval. The genital operculum is oval. The mesosoma merges back into the metasoma without any sudden narrowing, just as in *Strabops thacheri* Beecher, from the Upper Cambrian, in which, however, the antemedian lateral eyes are rounder, the prosoma still more transverse, in fact, elliptical, and the metasomatic segments shorter. From the stratigraphical point of view it is very suggestive to find such a primitive form as *D. bembycioides* in the Silurian of the Pentland Hills—especially when we think of the high degree of specialization in that apparently pre-Cambrian creature *Protadelaidea* Edgworth David, and Tillyard (1936).

Drepanopterus pentlandicus Laurie differs from *D. bembycioides* in the horseshoe-shaped prosoma, narrower " shovel " margin, more posterior position of the eyes, and a slight broadening of the mesosoma as far back as the fourth segment. The telson is also nearly half as long as the body. This all helps to indicate the relationship with *Stylonurus* ; and the closest foreign affinity is evidently with *Stylonurus* (*Drepanopterus*) *longicaudatus* Clarke and Ruedemann (1912, p. 288, etc., pl. 25, fig. 1, pls. 54–6) from the Kokomo waterlime, which has

been correlated with the Lockport of New York State, and which may be either Gala-Tarannon or Wenlock in age.

Drepanopterus lobatus Laurie (1899, pl. iii, fig. 18) differs from other *Drepanopteri* in the marked elongation of the third joint of Appendage VI. It also has a spine arising from one of the distal joints in Appendage V. This points to evolution towards a form like *Eurypterus* (*Onychopterus*) *kokomoensis* (Miller and Gurley). The broad prosoma of *D. lobatus* also suggests a parallelism with that of *Eurypterus ranilarva* Clarke and Ruedemann, also from the Kokomo waterlime, in which there are terminal short spines on the walking appendages and swimming paddles.

That " martial beast " *Carcinosoma scoticum* is compared by its author (Laurie, 1899, p. 587) with *C. scorpioides* (Woodward), from the " uppermost Silurian " of Logan Water, Lesmahagow, and with *C. punctatum* (Salter) which is founded on fragments from the Lower and Upper Ludlow. But the mesosoma of *C. scoticum* is relatively less wide in proportion to the tail-like metasoma than in other *Carcinosomata.* In America the nearest relative is *C. newlini* Claypole, from the Kokomo. One difference is that the terminal joint of Appendage III has three spines in *C. newlini* as against two very long ones in *C. scoticum.* Another is that the triangular plates lying between the final and penultimate joints of the paddles are even larger in *C. scoticum* than in *C. newlini.* Two ensiform telsons may belong to *C. scoticum,* and relate it to the pre-Guelph *C. logani* (Williams) (1915, pp. 8–9). They have a " herring-bone " ornament. Broken fragments might readily be mistaken for *Monograptus colonus* (Barrande), as in the case of *Stylonurus ornatus.*

Bembycosoma pomphicus Laurie has a broad semicircular, or " ace of clubs ", prosoma—possibly the shape has been affected by compression—and this is followed backwards by ill-defined segments of an evenly tapering mesosoma and metasoma, with terminal slightly concavo-conical telson. If we judge from *Drepanopterus,* the warty ornament of *Bembycosoma* is also a primitive feature.

Taken as a whole, the Eurypterids of the Pentlands probably possess a greater number of primitive features than any other large group of Eurypterids in any division of the Silurian. This provides a strong argument for ascribing an early date—*i.e.* Gala-Tarannon—to the formation at the Gutterford Burn where they are found.

It may be added that probable Eurypterid tracks in the Hardie Collection correspond with those figured by Salter (1866, p. 71, fig. 19) from Ellemford on the Whiteadder, below Longformacus, East Berwickshire.

A final point in this argument from the affinities of the Pentland Arachnida, is that Malcolm Laurie (1899, p. 578) looked on his

Palaeophonus loudonensis from the Gutterford Burn as older than *P. nuncius* Thorell, from Gotland, and other Silurian scorpions from Scotland and America.

(*r*) *Pisces*

The main stratigraphical problem which now arises concerns the exact age, within the Silurian, of the faunas in the " red beds " which in the Pentlands lie above the Igneous and Chert Pebble horizon. The lists of invertebrates announced by Peach and Horne (1899, pp. 600–1) do not seem to differ greatly from those of the Gala-Tarannon ; but where *Birkenia elegans* Traquair, *Ateleaspis tessellata* Traquair, and *Lasanius problematicus* Traquair, occur in the Lynslie Burn the associated species, including *Glauconome* and *Spirorbis*, are somewhat different. One connects this with the transition to brackish and fresh-water conditions, but there appears to be little evidence of a major break. While further field work is obviously necessary, the likely conclusion is that these primitive fishes may not be later than Wenlock. This is quite in keeping with the extremely primitive organization of *Birkenia* (Stetson, 1928A, Westoll, 1945).

If one applies the new stratigraphical interpretation to the Lesmahagow and Muirkirk areas, one may suppose that, in Peach and Horne's table of strata (1899, p. 569), items 1–3 are mainly Gala-Tarannon, up to and including the *Ceratiocaris* beds and the " Ludlow " fish band with *Thelodus planus* Traquair and common Pentland lamellibranchs like " *Anadontopsis bulla* " and *A. lucina* Salter (Peach and Horne, 1899, p. 572). It is possibly significant that in later—alleged " Downtonian "—beds of the Lesmahagow inlier, Peach and Horne record the characteristic Gutterford Burn species *Stylonurus ornatus* Laurie, along with a suite of the primitive fishes including *Lanarkia spinulosa* Traquair, *L. horrida* Traquair, *L. spinosa* Traquair, *Thelodus scoticus* Traquair, *Birkenia elegans, Lasanius problematicus*, and *Ateleaspis tessellata* (1899, p. 578).

The general conclusion seems to be that we are dealing with neritic and fresh-water faunas in formations which are thick in these northern regions, but which thin out towards the south to give, for example, the pseudo-conformity between the Upper Llandovery and the Wenlock Shales of Shropshire and the English Midlands. As well as in the Pentland Hills, there is evidence of emergence of a Gala-Tarannon island in the Melrose area, where Lapworth in his first geological paper (1870) recorded Eurypterids along with graptolites of the *Monoclimacis crenulata* Zone. Further notes on this area may be found in Wilson (1890) and in Pringle and Eckford (1945). On the south side of the Silurian geosyncline, homotaxial beds may appear in disputed formations at Clincher's Mill, west of the Malverns, and in the Tortworth

inlier, and in the Ferriter's Cove strata in South-West Ireland, where one is tempted to inquire about a possible comparison between the Silurian volcanics of County Kerry and those represented by tuffs in Kincardineshire.

On the Raeberry Castle coast, south of Kirkcudbright, in Scotland, it should be noted that *Cyrtograptus murchisoni*—the zonal fossil of the lowest Wenlock—has been recorded (Peach and Horne, 1899, p. 553). This suggests that the shelly fauna at Balmae Bay and Little Balmae farm may be either Lower Wenlock or related to the Pentland Hills shelly species. Thinning southwards of the Gala-Tarannon from a north-western landmass might account for the deposition and preservation of later beds on the southern frontier of Scotland.

More decisive evidence of the Wenlock must, however, be searched for. The earlier assumptions from which hitherto John Henderson (1874, p. 390 ; 1880, p. 356) was the only dissentient, have now been challenged.

Dr. John Pringle and George Ross concluded that there was no evidence of Upper Ludlow beds in the Lesmahagow district or—by implication—in the Pentland Hills (1930, p. 634), but they did not go far enough.

T. Stanley Westoll (1945, pp. 343, 354–6) has also encountered difficulty in regarding any of the strata in the Pentland Hills, or at Stonehaven, or in Lanarkshire as " Downtonian "—or even " Upper Ludlow ".

As a final suggestion one may add that in the Pentland Hills the emergence of land with fresh-water streams and estuaries was probably associated with a local phase of the Caledonian orogeny, which began in this area in Gala-Tarannon times with axes of folding running N.N.E.–S.S.W., like those of the post-Arenig–pre-Caradocian orogeny, the effects of which have recently been described in North Arran (Anderson and Pringle, 1944) and elsewhere (Lamont, 1945).

Folding probably on an E.N.E.–W.S.W. strike at the end of the Ashgillian has been demonstrated in Ayrshire (Lamont, 1935), but a difficulty arises since early Devonian—true Caledonian—folding was probably also on this strike.

A problem that remains is the one posed by Dr. R. Campbell (1913, pp. 934–6) as to why the Lower Old Red Sandstone is unconformable on the red beds of the alleged " Downtonian " in the Pentlands and in Ayrshire, whereas in Lanarkshire and Kincardineshire there is only disconformity. Maybe, folding was more intense along certain crest-lines between which younger, flat-lying beds were preserved—e.g. at Lesmahagow and Stonehaven—before Lower Old Red deposition commenced.

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On *Dayia navicula* (J. de C. Sowerby) and *Whitfieldella canalis* (J. de C. Sowerby) from the English Silurian

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DURING 1931–4 several hundred specimens of these two species were collected, including a quantity of excellently preserved silicified material from an exposure of the Dayia Shales (Elles and Slater, 1906, pp. 197 and 198), near Norton in Shropshire. Serial sections and development of the material have made possible the detailed descriptions which follow.

DAYIA

Dayia.—Davidson, 1881, " On the genera *Merista*, Suess, 1851, and *Dayia*, Davidson, 1881." *Geol. Mag.*, xviii, 291.

Genotype.—*Terebratula navicula* J. de C. Sowerby, 1839.

Diagnosis.—Articulate brachiopod of small size with short, gently curved hinge-line. Elongate sub-pentagonal outline, surface smooth. Greatest width and depth just anterior to the hinge line. Pedicle valve the larger with strongly incurved umbo ; high rounded keel flattening anteriorly, lateral slopes plane. Brachial valve slightly convex with shallow, ill-defined median sinus. Lateral commissure with gentle dorsal flexure, anterior commissure straight.

Pedicle valve with large teeth at ends of hinge line, no dental plates. Muscle impression wide, divided into three pairs, anterior edge V-shaped with the apex directed posteriorly. No vascular or genital impressions seen.

Brachial valve with kidney-shaped cardinal process supported on low, thick septum passing anteriorly into a low ridge dividing the muscle impression. Stout crural bases distant from cardinal process and fused to the inner socket wall posteriorly. Crura short, directed anteriorly. Primary lamellae running first laterally and then anteriorly. First ascending lamella directed postero-ventrally. Spires directed laterally. Jugum directed towards the centre of the shell. Jugal process fairly long, simple, directed posteriorly. Muscle impression faint, elongate.

Shell structure two-layered, inner layer very thick in posterior part of pedicle valve.

Typical proportions : length 11 mm., breadth 8 mm., depth 8 mm.

DAYIA NAVICULA

Terebratula navicula J. de C. Sowerby, 1839, in Murchison, *The Silurian System . . .*, Pt. ii, 611, pl. v, fig. 17.

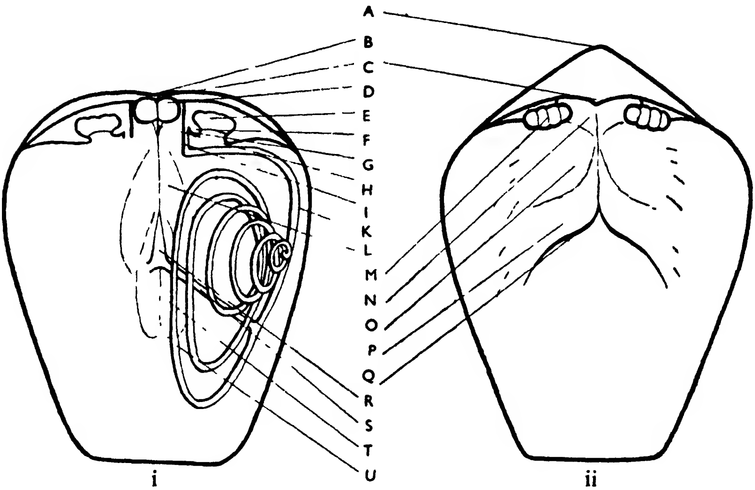
Holotype.—No. 51549, Geol. Soc. Coll., Geological Survey and Museum, Upper Ludlow, Shelderton Lane, Shropshire.

Diagnosis.—As for genus.

Description.

External Characters (Text-fig. 4)

The high, rounded keel of the pedicle valve becomes flattened anterior to the middle of the shell. Thus cross sections typically



Text-fig. 1.—Reconstruction of *Dayia navicula* (J. de C. Sowerby) × 5 approx., based on sections, internal moulds, and silicified specimens. i = brachial valve, ii = pedicle valve. A = keel, B = sinus, C = umbo, D = cardinal process, E = dental socket, F = inner socket wall, G = crural base, H = septum, I = crus, K = primary lamella, L = posterior adductor impression, M = tooth, N = diductor impression, O = posterior adductor impression, P = anterior adductor impression, Q = anterior edge of muscle callosity, R = jugal process, S = arm of jugum, T = anterior adductor impression, U = first ascending lamella.

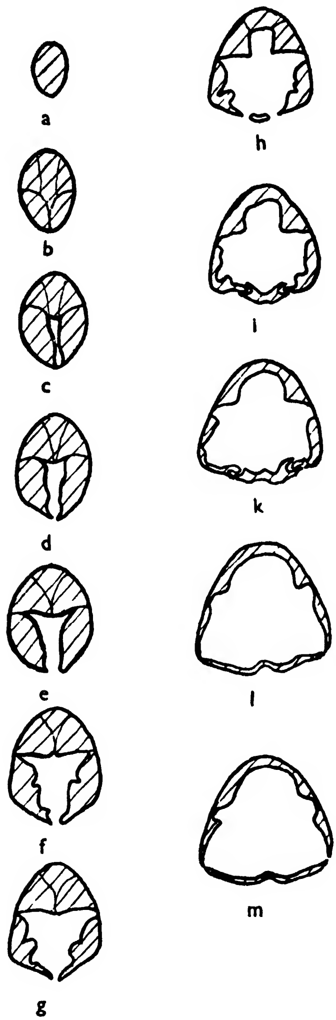
appear as equilateral or acute angled isosceles triangles posterior to the middle and as truncated isosceles triangles anterior to the middle. The centre part of each of the lateral slopes of the pedicle valve is slightly extended, giving a dorsal flexure to the lateral commissure. Anteriorly the shell is sharply truncated and the commissure is straight.

The brachial valve is almost plain, but is slightly convex in the umbonal region on either side of the median line. The sinus is always ill-defined and becomes more shallow anteriorly.

Both valves are entirely without ornament.

INTERNAL CHARACTERS (Text-figs. 1 and 3)

Pedicle Valve.—The teeth are very large outgrowths of the inner shell layer at the ends of the hinge-line, and may be crenulated on the dorsal



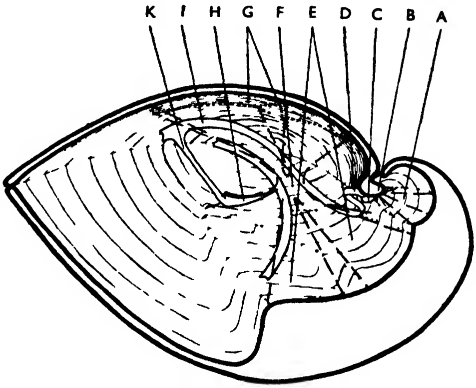
TEXT-FIG. 2.—Series of transverse sections through the umbonal part of *D. navicula* × 3. A 11,212, Sedgwick Museum Collection, Dayia Shales, Brandhill, Shropshire.

Interval between sections in millimetres :—

a–b = 0·465, *b–c* = 0·38, *c–d* = 0·135, *d–e* = 0·34, *e–f* = 0·065, *f–g* = 0·195, *g–h* = 0·29, *h–i* = 0·18, *i–k* = 0·475, *k–l* = 0·395, *l–m* = 0·15. Pedicle valve uppermost.

face. The muscle impression is striking and is composed of three pairs of impressions. Close to the hinge there is on each side of the median line a trapezoidal impression. Directly anterior to this is a pair of large, roughly triangular impressions, the apex of the triangle lying at the middle line of the shell. The anterior edge of this pair of impressions is terminated by a slight groove lying along the posterior margin of a V-shaped callosity. A pair of rectangular impressions lie on the posterior face of this callosity.

The whole muscle impression lies on a much thickened part of the valve. This thickening diminishes gradually at the sides and very



TEXT-FIG. 3.—Lateral view, from the middle plane, of *D. navicula* (Sow.) × 5 approx. A = area of attachment of diductor muscles in pedicle valve, B = cardinal process, C = tooth, D = crus, E = area of attachment of adductor muscles in pedicle valve, F = tendonous portion of adductor muscles, G = area of attachment of adductor muscles in brachial valve, H = jugal process, I = primary lamella, K = arm of jugum.

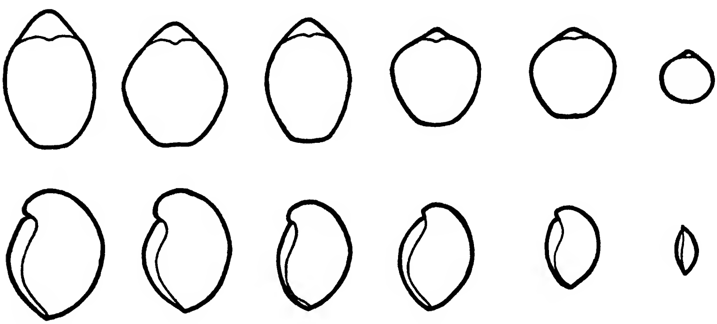
abruptly at the anterior end of the muscle impression. Thus the muscle callosity in this species is a step in, and not a ridge on, the valve floor.

Brachial Valve.—The large kidney-shaped cardinal process has a deep median groove. It is supported on a very low, thick septum which is produced anteriorly as a rounded ridge running through the muscle impression. The stout crural bases are distant from the cardinal process. Posteriorly they are fused to the inner socket wall, but the two structures become separate at their anterior ends. The thickened hinge and valve margin form the posterior and outer socket walls respectively.

The short, straight crura are directed anteriorly, the primary lamellae being given off laterally from their tips. On approaching the valve margin, the primary lamellae turn anteriorly, following its curve till at a point about two-thirds of the way along from the umbo they

curve slightly towards each other. From here the arms of the jugum are directed towards the centre of the shell, while the primary lamellae continue for a short distance and then turn towards the pedicle umbo as the first ascending lamellae. The jugum is complete and carries a simple, fairly long, dorsally directed jugal process, which makes an obtuse angle with the plane of the jugum.

Each spire consists of about seven turns with the apex directed laterally. The dorsal portions of the first three turns are tilted laterally in respect of their ventral portions. Thus each spire is shaped like a sombrero with one-half of the brim turned up. The anterior parts of the primary and first ascending lamellae are frequently fimbriated.



a b c d e f

TEXT-FIG. 4.—Outline drawings of six individuals of *D. navicula* (Sow.) × 1½.
a and *b* adult, *c* to *f* immature.
a = A 11,185, *b* = A 11,187, *c* = A 11,188, Sedgwick Museum Collection, Dayia shales, Brandhill, Shropshire.
d = A 11,196, *e* = A 11,197, Sedgwick Museum Collection, Dayia shales, Shelderton, Shropshire.
f = A 11,200, Sedgwick Museum Collection, Dayia shales, Aldon, Shropshire.

The narrow elongate muscle impression is divided into two pairs of impressions by low, oblique ridges.

Musculature.—It appears probable that the diductor muscles ran from the cardinal process to the posterior of the three pairs of impressions in the pedicle valve (i.e. from B to A in Text-fig. 3). Similarly the adductor muscles probably ran from the elongate impression in the brachial valve through a tendonous portion to the two anterior pairs of impressions in the pedicle valve (i.e. from G to E in Text-fig. 3). The diductor muscles would thus be posterior to the whole of the brachidium, while the adductor muscles would pass between the posterior portions of the primary lamellae and would be posterior to the jugum.

The common occurrence of complete specimens with the posterior part filled with detritus and the anterior part with calcite or silica indicates that the shell rested on the posterior part of the pedicle valve, at least after the death of the animal. The distribution of weight in the shell and the absence of any mechanism for keeping the shell in any position other than that of maximum mechanical stability makes it appear probable that the animal lived in this position. If the animal lived with the heavy keel downwards the valves would tend to open under the influence of gravity and this may be connected with the very small development of the diductor muscles and the very large development of the adductor muscles.

Shell Structure.—The outer shell layer is thin, covers the outer surface of both valves, and is composed of lamellae directed forward and inward.

The lamellae of the inner shell layer, which lines both valves and forms all the inner structures, are subparallel to the surfaces which they form. This layer is moderately thick over the whole of the brachial valve, and in the anterior and lateral parts of the pedicle valve It is very thick in the posterior part of the pedicle valve, where it consists of two overlapping parts. In the umbonal region there is a moderately thin development of the inner shell layer, which thickens up to the anterior edge of the muscle impression and then thins rapidly towards the valve margin. The teeth and hinge are formed of a second thickening of the inner shell layer, which is produced forward over the first as far as the anterior margin of the posterior diductor impression. The thickening of the inner shell layer is a function of the curvature of the pedicle valve, and hence of the age of the individual. In young individuals the pedicle valve is not strongly curved, the shell is thin and the muscle callosity faint. In the adult the curvature of the pedicle valve is very strong, the shell very thick and the muscle callosity marked. This thickening of the pedicle valve in the area of muscle attachment in effect keeps the inner surfaces of the two valves in constant relation to each other, so that throughout the life of the individual the muscles pull at a constant angle to the surfaces to which they are attached.

Variation.—The species is not very variable. Individuals are usually elongate, but occasionally the breadth is nearly as great as the length. Typically, breadth and depth are equal, but either dimension may exceed the other. In very young individuals, up to 4 mm. long, the valves are almost circular in outline and subequally convex. With increasing age the typical shape is rapidly gained, though the depth does not become equal to the width till the animal is nearly adult.

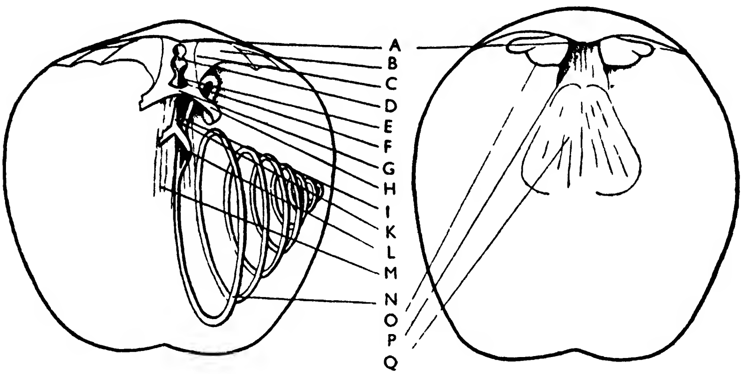
Horizon and Locality.—*Dayia navicula* occurs in great numbers in the calcareous beds immediately overlying the Aymestry Limestone of the Welsh borderlands, to which beds it gives its name (Elles and

Slater, 1906, pp. 197–8). In this area it is rare in the Lower Ludlow shales and Aymestry Limestone. Farther west it occurs in bands throughout the Ludlow (see Shirley, 1939, pp. 360, 361, and Davidson, 1869 (iii), p. 190). On the continent of Europe the species is widespread and has been reported from the top of the Ordovician and throughout the Silurian (see Barrande, 1879, p. 17; Kozlowski, 1929, pp. 4, 15, 25, 179–81; Richter, 1937, pp. 303–309).

WHITFIELDELLA

Whitfieldella Hall and Clarke, 1894. *Nat. Hist. N.Y. Pal.*, viii, pt. 2, 58–61, pl. xl. (In the original description, the plate number is given as xlviii in error.)

Genotype.—Atrypa nitida Hall, 1843. *Geol. Rept.*, 4 *Dist. N.Y.* Tables of organic remains of Niagaran Group, No. 14, fig. 5.



TEXT-FIG. 5.—Reconstruction of *Whitfieldella canalis* (Sow.) × 4 approx., based on serial sections, internal moulds, and silicified specimens. i = brachial valve, ii = pedicle valve. A = umbo, B = socket, C = inner socket wall, D = septalium, E = septum, F = visceral foramen, G = plate connecting crural bases, H = crus, I = primary lamella, K = jugal process, L = jugum, M = adductor muscle impression, N = first ascending lamella, O = tooth, P = diductor muscle impression, Q = adductor muscle impression.

Diagnosis.—Articulate brachiopod of small size with short, slightly curved hinge-line. Circular, oval, or triangular in outline. Valves subequally convex. Anterior margin truncated. Median sinus in each valve. No ornament, growth lines faint. Pedicle umbo incurved, narrow deltherium closed anteriorly by deltidial plates.

Pedicle valve with teeth supported on short, high dental plates at end of divided hinge-line. Adductor impression large, distinct; diductor, vascular and genital impressions faint.

Brachial valve with divided hinge supported posteriorly on low, open septalium. Crural bases connected by thin plate at anterior ends.

Crura short, directed antero-laterally from tips of crural bases. Primary lamellae fiıst directed posteriorly and then anteriorly along valve floor. Spires directed laterally. Jugum complete, directed ventrally and carrying short, simple, posteriorly directed process. Dental sockets simple. Muscle, vascular and genital impressions faint. Shell two-layered, both lamellar.

WHITFIELDELLA CANALIS

Terebratula canalis.—J. de C. Sowerby, 1939. In Murchison, *The Silurian System* . . ., p. 611, pl. v, fig. 18.

Holotype.—No. 6614, Geol. Soc. Coll., Geological Survey and Museum, Upper Ludlow, near Uske.

Selected Synonymy.—*Atrypa didyma* (Dalman) J. de C. Sowerby, 1839, in Murchison, *The Silurian System* . . ., p. 614, pl. vi, fig. 4.

Meristina didyma (Dalman), Davidson, 1867, *Brit. Foss. Brach*., iii, pt. vii, 112, pl. xii, figs. 1–10.

Meristina didyma (Dalman), Davidson, 1882, *ibid*., v, 94–6, pl. iv, figs. 22–3.

Diagnosis.—*Whitfieldella*, subpentagonal in outline, pedicle umbone strongly incurved usually concealing foramen ; dental plates thin, muscle impression sub-triangular. In the brachial valve the septum is very low, the jugal process very short ; the spires have about seven turns.

Typical proportions : length 11 mm., breadth 10 mm., depth 8 mm.

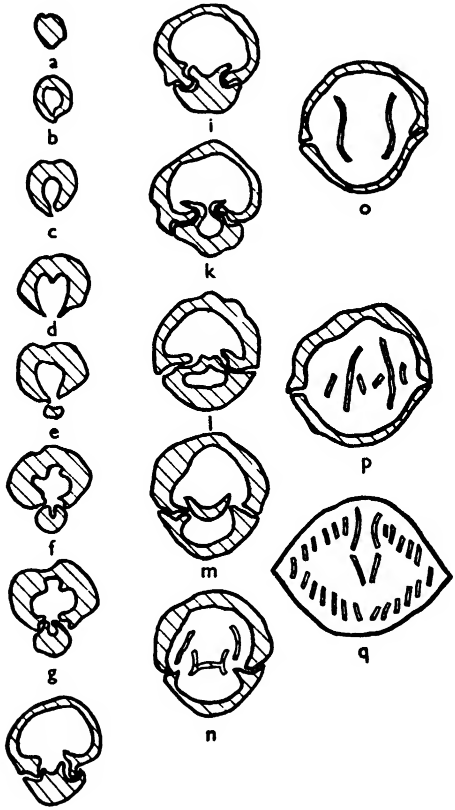
Remarks.—The holotype of *Whitfieldella canalis* is a pedicle valve, doubtless originally subcircular in outline, but crushed during fossilization.

Individuals of this species have in the past been referred to Dalman's *Terebratula didyma* (Dalman, 1828, p. 146, pl. vi, fig. 17). Davidson also considered that *T. didyma* Dalman, 1828, and *Atrypa nitida* Hall, 1843 (Hall, 1843, No. 14, fig. 5) were identical, and found that the brachidia of the specimens (from Gotland and America) which he examined were the same as that in the British specimens referred to *T. didyma* (Davidson, 1882, p. 95). He therefore made *T. canalis* J. de C. Sowerby, 1839, and *A. nitida* Hall, 1843, synonymous with *Meristina didyma* (Dalman, 1828).

In 1894, Hall and Clarke proposed the genus *Whitfieldella* with genotype *Atrypa nitida* Hall, and at the same time drew attention to the differences in the external characters of *W. nitida* (Hall) and *T. didyma* auct. (Hall and Clarke, 1894, pp. 58–61).

In 1929, Kozlowski proposed the genus *Protathyris* for some Polish species which are similar to *T. didyma* Dalman, in external characters (Kozlowski, 1929, p. 223). One of the diagnostic characters of this genus is a peculiarly forked jugal process, and Kozlowski found this

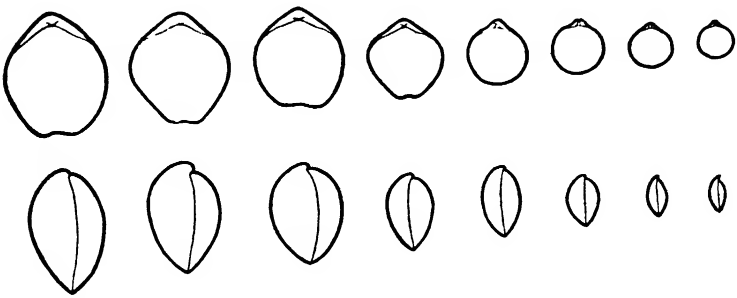
character in specimens (from the Island of Oesel) which agree externally with Dalman's figures and description of *T. didyma* (Kozlowski, 1929, p. 224). Kozlowski therefore placed *T. didyma* Dalman, in the genus *Protathyris,* and pointed out that the British *T. didyma* auctt. was a different species.



TEXT-FIG. 6.—Series of transverse sections through an individual of *W. canalis* (Sow.) × 3. Intervals between sections in millimetres :—
a–b = 0·2, *b–c* = 0·32, *c–d* = 0·36, *d–e* = 0·8, *e–f* = 0·21, *f–g* = 0·08, *g–h* = 0·28, *h–i* = 0·17, *i–k* = 0·07, *k–l* = 0·09, *l–m* = 0·07, *m–n* = 0·04, *n–o* = 0·3, *o–p* = 0·73, *p–q* = 4·27.

A careful examination of British material makes it clear that the species has the characters of the genus *Whitfieldella,* and that it can be distinguished from *W. nitida* (Hall) and *P. didyma* (Dalman) by internal and external characters.

Whitfieldella canalis (Sowerby) differs from *Protathyris didyma* (Dalman) in being smaller, more markedly pentagonal in outline, having a strongly incurved umbone and having only faint, short sinuses. In the British species the bilobed muscle impression in the pedicle valve is rather faint and never enclosed by the ridges running from the dental plates. In the Swedish species the muscle impression is totally enclosed. In the brachial valve the very short, simple jugal process and the short septum distinguish *W. canalis* (Sow.) from *P. didyma* (Dalman), which has a long, forked jugal process and no septum.



a b c d e f g h

TEXT-FIG. 7.—Outline drawings of eight individuals of *W. canalis* (Sow.) × 1⅛. approx. *a*, *b*, and *c*, adult ; *d* to *h* a series in decreasing age.
a = A 11,172, Sedgwick Museum Collection, Dayia shales, Norton, Shropshire.
b = A 11,174, Sedgwick Museum Collection, Aymestry Limestone, Cophall, Herefordshire.
c = A 5,565, Sedgwick Museum Collection, Aymestry Limestone, Sedgley, Shropshire.
d = A 11,176, *e* = A 11,181, *f* = A 11,178, *g* = A 11,179, *h* = A 11,182, Sedgwick Museum Collection, Aymestry Limestone, Norton, Shropshire.

Whitfieldella nitida (Hall) is twice the size of *Whitfieldella canalis* (Sowerby), is oval to triangular in outline, has a slightly incurved umbo and long faint sinuses. The muscle impression in the pedicle valve is flabellate in the American species. In the brachial valve a long distinct septum, a long jugal process and four widely separated muscle impressions distinguish *W. nitida* (Hall) from *W. canalis* (Sowerby) in which the muscle impression is faint and elongate.

Description.

EXTERNAL CHARACTERS (Text-fig. 7)

In the very early stages the valves are circular in outline, only slightly convex and the pedicle umbo is erect. With increasing age the valves become deeper, the pedicle umbo more and more incurved,

and the valve outline gradually takes on a pentagonal shape. The widest and deepest part of the shell retreats from the centre to a point between the hinge and middle line. In the adult the pedicle umbo nearly touches the dorsal valve, and the pentagonal outline of the shell is marked. Though the length and breadth are generally nearly equal, the former may be slightly the greater, giving rise to elongate individuals. The sinuses are very faint in this species, and are never developed until late in life. Frequently the only indication of a sinus is the slight indentation of the anterior margin. The valve surfaces are quite smooth, even the growth lines being scarcely visible.

Internal Characters

Pedicle Valve (Text-fig. 5, ii).—The unmodified, thin dental plates are visible in young individuals only, in which they diverge more or less strongly from the umbone, ending abruptly anteriorly. With increasing age the space between the dental plates and the valve becomes gradually filled, commencing at the umbone, while the median cavity is hardly affected. This causes the peculiar " beak " seen in so many internal casts of the pedicle valve of this species. A low, short ridge runs anteriorly from the base of each dental plate and bounds the posterior lateral part of the muscle impression. Each tooth carries a small lateral boss.

Between the dental plates there is an area which is faintly striated. It appears to be the trace of the adductor and pedicle muscles, the pedicle probably being functional up to the adult stage. Anterior to this area is a well marked impression bisected longitudinally, whose lateral portions may run parallel to each other giving an elongate impression, or they may diverge more or less strongly giving a bilobed, triangular impression. This is certainly the diductor impression.

The vascular markings are faint, radiating grooves originating from the sides and end of the diductor impression. Genital markings consist of a few shallow pits in the valve surface on either side of the posterior portion of the diductor impression.

Brachial Valve.—The hinge is supported centrally by a septalium carried on a low septum which, at the anterior edge of the hinge-plate, degenerates into an extremely low ridge dividing the muscle impression longitudinally. Each half of the hinge-plate consists of two portions, a massive plate constituting the crural base and inner socket wall and a thin plate, concave anteriorly, running from the inner socket wall to the valve margin. This plate, which forms the posterior socket wall, has a low ridge near the antero-lateral corner which divides the socket into a main median portion and a small lateral portion. The valve margin forms the outer socket wall. Each inner socket wall—crural base-plate is produced anteriorly beyond the

septalium and they are connected at the anterior end by a thin plate. The foramen posterior to this plate corresponds with the visceral foramen noticed by Kozlowski in *Protathyris* (Kozlowski, 1929, p. 223).

The short, stout crura are directed antero-laterally from the tips of the crural bases. The primary lamellae run postero-dorsally from the tips of the crura till they are close to the floor of the valve. They then curve anteriorly, keeping close to the valve floor and converging on the centre. From the centre they diverge again and turning towards the pedicle valve form the first ascending lamellae. The spires are formed of about seven turns, the apices being directed laterally. Just posterior to the point at which the primary lamellae most nearly approach each other a branch, directed towards the pedicle valve, is given off at right angles to the original lamellae. These two branches run parallel to each other to within a short distance from the pedicle valve. Here they turn sharply towards the umbo, unite and give off a short posteriorly directed spine at the point of junction. This loop and spine constitute the jugum and jugal process.

The muscle impression is extremely long (nearly half the valve length) and narrow. It is divided longitudinally by the low ridge extending from the septalium. No other subdivision of the muscle impression has been seen. Very faint radiating vascular impressions are sometimes visible.

Shell Structure.—The shell is composed of two thick lamellar layers. In the outer shell layer the lamellae run obliquely forwards and inwards. The inner shell layer is thickest in the umbonal region and area of muscle attachment in the pedicle valve. It lines almost the whole of each valve, disappearing a short distance within the anterior margin. All the internal structures are formed of this layer the lamellae in which run subparallel to the surfaces which they form. Thickening of the inner shell layer in the adult leads to the filling of the lateral umbonal cavities of the pedicle valve and sometimes to the welding of the hinge-plate of the brachial valve to the valve floor.

Horizon and Locality.—Whitfieldella canalis occurs chiefly at the top of the Aymestry Limestone in the British Isles. It is common at this horizon near Craven Arms in Shropshire and at Sedgley in Staffordshire, but is rather rare elsewhere. It also occurs in the Wenlock Limestone.

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REVIEWS

LES FORAGES PROFONDS DU BASSIN DE PARIS. By PAUL LEMOINE, RÉNÉ HUMERY, and ROBERT SOYER. 1939. Masson & Cie., Paris. (Extrait des Museum National d'Histoire naturelle. Nouvelle serie, tome xi.)

This useful compilation of bore hole data allows ready access to all the information available on the sub-surface geology of the Paris Basin. Although the primary object of the work is to provide a record of the Albian greensand from the water supply point of view, it will greatly assist anyone interested in the factual data of Jurassic and Cretaceous geology. The book's 700 pages contain 425 pages giving a detailed description of the strata encountered in the bore holes. The location of the bore holes is shown on a map on the scale of one millionth, which also incorporates information on the age of the floor on which the Albian greensand rests. In addition to the detailed well descriptions there are two sets of tables, one set giving depths to formation boundaries from the surface, the other giving depths referred to sea-level. There is an index of bore holes and a 19-page bibliography. The descriptive introductory chapters deal with various aspects of the Paris Basin—its limits and general stratigraphy; the Albian; its subsidence and tectonics. There are also ten chapters which discuss water supply questions.

The book should form a valuable addition to all main geological reference libraries.

It is perhaps worth noting that in a few cases some of the data given in the tabular summaries have stepped up or down a line in printing, and are now opposite the wrong bore hole name. It is advisable, therefore, to check these figures with the detailed descriptions before using them.

N. L F.

WATER SUPPLY FROM UNDERGROUND SOURCES OF THE CAMBRIDGE–IPSWICH DISTRICT, QUARTER-INCH GEOLOGICAL SHEET 16. Geological Survey and Museum. Wartime Pamphlet No. 20, by A. W. WOODLAND. 1946, price 4*s*.

In Part X of Wartime Pamphlet No. 20, Dr. Woodland brings together in a masterly fashion the information on water supply from underground sources in southern East Anglia. The first nine parts of this pamphlet give the records for wells and bore-holes, but this tenth part is an excellent example of how a mass of detail can be synthesized and important conclusions of a more general nature drawn from their study.

Amongst the numerous maps is one showing the presence of large extensions of the Pliocene Crags north-east of Stowmarket, while others include valuable isopachyte figures, static water levels, chlorine content, etc. All these maps will be of the greatest value in enabling the thickness of the strata and quality of water to be estimated with ease at any point. It has long been known that in parts of the area the Chalk was not a good water-yielding formation. Dr. Woodland has divided the area into four classes on yield value and mapped the distribution of these classes. This map will be of the greatest value to anyone proposing to obtain water by means of bore-holes into the Chalk.

In dealing with the variation of water-level, Fig. 11 gives the average position over the year. In some ways these average figures are misleading, since the rise from autumn to winter always appears much less steep than is actually the case, as can be seen from Fig. 12, which gives the actual water table movement.

This work is much more than of local value, for the principles discussed and particularly the methods of presentation used are applicable to much wider areas. Dr. Woodland is to be congratulated upon a most valuable contribution.

W. B. R. K.

AN INTRODUCTION TO CRYSTALLOGRAPHY. By F. C. PHILLIPS. Pp. ix × 302, with 500 Text-figs. London, Longmans, Green, and Co., 1947, price 25*s*.

This book is an elementary exposition of the science to which the Cambridge school has contributed so liberally since Miller's classical essay of 1839. It is divided into two parts, the first dealing with the external symmetry of crystals and the second with the symmetry of the internal arrangement. The author's experience of teaching has led him to use the historical approach and to make lavish use of crystal drawings, projections, and diagrams. These are outstanding in their clarity and almost entirely free from those trivial mistakes which can be such a distressing hindrance to the beginner.

Professor Phillips can also claim the distinction of having written the first textbook on the morphology of crystals to adopt the Hermann-Mauguin notation for the thirty-two crystal classes and the discussion of space-groups. The clumsy, less informative names of the crystal classes are relegated to a bracketed, secondary position and the Schoenflies notation to an appendix. He fortunately extends the same systematic and logical treatment to the study of space-groups as to that of crystals and has provided the student of physics, chemistry,

and mineralogy with a first-rate introduction to the use of the space-group diagrams in the International Tables.

It is easy to commend the author for pursuing his theme to the threshold of crystal structures and no further. He has achieved thereby a shorter and a better book. One would have liked, however, to see the obvious relation between Haüy's " molecule integrante " and the unit cell of the X-ray crystallographer explicitly stated. The sooner the student learns that the size of the unit of pattern of the crystal fabric can be measured the better. Why deny him the simple and logical derivation of the indices of crystal faces direct from the unit cell dimensions ? Let him learn later that his less fortunate predecessor had to employ a more cumbersome derivation involving the choice of a parametral plane and axial ratios. One also questions the wisdom of introducing students to the limited truth of the Donnay-Harker principle. No one is likely to embark on the determination of a space-group with an optical goniometer, when the X-ray method is so well established and certain. That instrument is much more likely to be employed, as it was formerly, for the determination of class symmetry and perhaps also applied to a more energetic attack on the problems of crystal growth and the study of the large-scale imperfections of real crystals.

F. A. B.

CORRESPONDENCE

GALA-TARANNON BEDS IN THE PENTLAND HILLS, NEAR EDINBURGH

SIR,—Since my paper on the Gala-Tarannon Beds went to the press, a new graptolite assemblage has been collected from the base of a contorted sandy siltstone at Gypsy Point, south of Kirkcudbright. Dr. G. L. Elles has kindly identified the following forms : *Cyrtograptus carruthersi* Lapworth, *C. lundgreni* Tullb., *Monograptus dubius* Suess, *M. flemingi* Salt., *M. flemingi* var. *compactus* (Elles). This is the youngest graptolite fauna so far recorded in the Southern Uplands. The beds containing it appear to be younger than beds with erosion features, dragmarks and ripplemarks further north.

A. LAMONT.

GRANT INSTITUTE OF GEOLOGY,
EDINBURGH.
August, 1947.

THE MALVERN FAULT

SIR,—Many years ago, when visiting Great Malvern under the guidance of a local geologist, whose name I am sorry to have forgotten, I was shown a temporary exposure in the rear of the westernmost row of buildings. This showed a very steep face of Archaean, with remains of a plastering of what appeared to be Bunter sandstone. The obvious interpretation was that here was a fault-plane, the first of a series of steps leading down to the Keuper marl below. The references to Murchison given by Mr. Falcon (*ante*, p. 236) are consistent with this observation and interpretation.

For the sentence of mine quoted by Mr. Falcon (footnote, p. 229), I must offer belated apologies. It was written at a time when my field experience of the Malvern area was almost nil.

A. MORLEY DAVIES.

AMERSHAM,
BUCKS.
23rd Aug, 1947.

THE MYNACHDY GNEISS

SIR,—In the *Anglesey Memoir* (p. 296) orthoclase is said to be found in the gneisses of Mynachdy. During my revision of the Blake Collection, I made a re-study of this slide (E. 10643), and found in it no orthoclase. A negative felspar there certainly is, but its refractive index differs but little from that of quartz.

The interest is much more than local, for this is the only remaining exception. We now can say with confidence that in unequivocal gneisses no orthoclase has ever been found.

EDWARD GREENLY.

AETHWY RIDGE,
BANGOR.
2nd July, 1947.

GEOLOGICAL MAGAZINE

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The Relation of Volcanicity and Orogeny to Climatic Change

By V. E. Fuchs and T. T. Paterson

THE purpose of this communication is to draw attention to the possible effect of vast and synchronous volcanic eruptions and associated earth-movement, not only on local but on world climate. It is divided into two parts, the first dealing with the volcanic aspect and its particular relation to climatic changes in East Africa, and the second discussing the wider significance of the proposition and the possibly greater effect of orogenic movements on world climate when associated with volcanic episodes.

It is hoped to be able to publish fuller and more detailed statements at a later date but other work does not permit at the present time.

We are indebted to Mr. Gordon Manley for numerous discussions and much advice on the meteorological aspects of the case.

PART I

The Volcanics of East Africa and Pluvial Periods

By V. E. Fuchs

In the course of preparing a paper on the Pleistocene geology of Lake Baringo, Kenya Colony, it was found that successive rises and falls of the lake were due to volcanic barrier building and the destruction of those barriers by faulting. At the same time it was observed that the fluctuations of the lake were comparable to those of other lakes in East Africa which have been attributed to increased precipitation during Pluvial periods. This apparent coincidence led to a consideration of the relationship of volcanics, earth-movement, and precipitation, for it had long been a source of speculation as to why the major pluvial periods in East Africa were ushered in by earth-movement and associated volcanicity. This fact was already commented upon by Wayland (1935), who refers to " rapidly changing conditions introduced by what must have been stupendous tectonic events, accompanied in Kenya and Tanganyika by widespread volcanism ".

The following proposition makes it possible to relate earth-movement and volcanics to rising lakes, and at the same time to avoid the necessity of invoking barrier building and destruction in each case.

W. J. Humphries (1913) showed that volcanic eruptions can and do affect world climate but he leaves it to geologists to show that there have been eruptions of sufficiently explosive character and continuity to have the more permanent effect required to initiate glacial conditions. This requirement is equally necessary when considering the relation of volcanics and pluviation in a smaller area such as East Africa.

Volcanics of East Africa

The Pleistocene eruptions of East Africa extend in association with the Rift Valley, for more than 900 miles, from Abyssinia to the Giant Craterland of Tanganyika. In the western arm of the rift a lesser Pleistocene volcanic episode also occurred, as witness the Bufumbiro Mountains, the explosive craters of Toro-Ankole, and to the south the Rungwe volcanics of the Nyasa-Rukwa rift.

Among the volcanoes of the Giant Craterland, Ngorongoro has a crater twelve miles in diameter [1] which with numerous other craters from Lemagrut to Ol Doinyo Lengai, form a fifty mile chain of eruptive centres rising to over 11,000 feet. The earliest eruptions occurred during the Lower Pleistocene, but the maximum activity was during the Middle Pleistocene, with a considerable but reduced activity in the Upper Pleistocene (Kent, 1944).

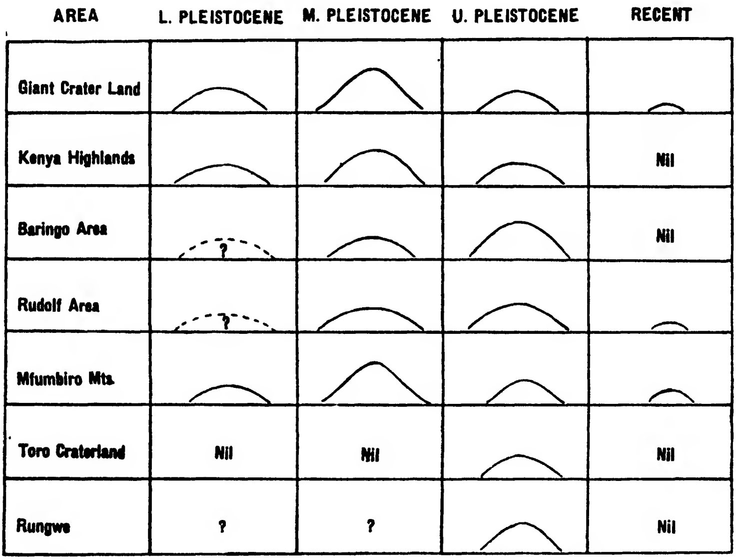
Further north, Shackleton (1945) has shown that in Kenya the volcanics of the Lower Pleistocene produced the quartz-trachytes of Maralal, Nairobi, and Ngong, besides the Laikipian basalts of the Aberdares, Simbara, and Laikipia, and the parasitic cones of Kenya. In Kenya also the Middle Pleistocene was a period of great eruption as shown by the enormous thickness of tuffs in the Kinangop area where some 1,500 feet are exposed by the rift faulting. These indeed are but the northern representatives of the Eyassi plateau some 200 miles to the south and themselves extend northward into the Baringo District.

Throughout the area numerous other but more isolated centres contributed their eruptions during the Lower, Middle, and Upper Pleistocene phases, for instance, Essimingor east of Lake Manyara Homa Mountain (Kent, 1942) of the Kavirondo Gulf area, and there is little doubt that the great volcano of Kilimanjaro (19,800 feet) was active as late as the Upper Pleistocene.

[1] Though strictly this is a cauldron, it is evidence of the sometime existence of a gigantic volcanic mass.

The widespread volcanic phase of the Upper Pleistocene is represented by the craters of Suswa, Longonot, Eburru, Menengai, to mention only a few of the better known names. In addition, there is a multitude of larger or smaller eruptive centres which have provided ample evidence of their widespread eruptions in the great quantities of ashes and tuffs which now overlie the faulted mid-Pleistocene volcanics. In the Baringo area this activity predominated in Korrossa, Pakka, and Silali besides innumerable lesser centres.

Further north in the Lake Rudolf area possibly Lower and certainly Middle and Upper Pleistocene volcanics are recognized (Fuchs, 1939),



TEXT-FIG. 1.—Diagrammatic representation of Pleistocene volcanicity in East Africa.

while in Abyssinia there are known to be extensive volcanics associated with the local rift movements of the Pleistocene but unfortunately there is little work which will serve to differentiate their age within that period.

In the western or Uganda rift area the greatest eruptions were those of the Bufumbiro range (Combe and Simmons, 1933) between lakes Edward and Kivu. There, eight volcanoes attain to a height of between 10,000 and 14,000 feet, and together with thirty-four smaller ones form a volcanic area about 1,500 square miles in extent. The age of the earliest eruptions has not been established with certainty but there is evidence of an early period of activity at the beginning of Pleistocene times followed by a break before the major eruptions of the Middle

Pleistocene. There is also ample evidence that these volcanoes were again active, but on a lesser scale, in the Upper Pleistocene.

Further evidence of Middle Pleistocene activity in the western rift is provided by the aqueous ashes which everywhere form the upper part of the Kaiso series (Holmes and Harwood, 1932). The innumerable explosion craters of Toro-Ankole on the other hand belong to the Upper Pleistocene phase.

Text-figure 1 shows diagrammatically the eruptive episodes of the East African area referred to. The relative degree of known activity within each area is arbitrarily represented by the amplitude of the curves.

The Relation of Volcanics to Precipitation in East Africa

Perhaps enough has been said to give an idea of the size and extent of the Pleistocene eruptions of East Africa, but it is well to emphasize the evidence of the enormous amount of material ejected by all these centres. The ashes and tuffs form not only the volcanic cones themselves but also immensely thick deposits over the area of the rifts and often contribute largely to the lake deposits which have been used to trace the rise and fall of the pluvials. It is not possible to consider here the effect of this ash cover on vegetation, rainfall run-off, depth of groundwater, and the whole complexity of the hydrological cycle (Meinzer, 1942), though this doubtless adds its effect to the primary process here propounded.

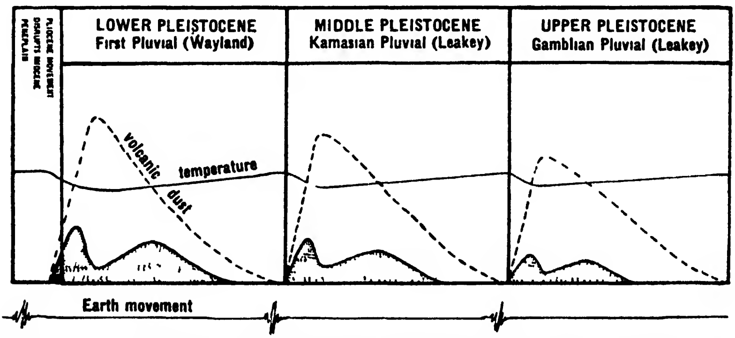
If as shown by Humphries, single explosions of modern volcanoes can affect the sun's radiation throughout the world for periods of two to three years, it seems reasonable to concede that the extensive eruptions of East Africa must have had at least a local, and possibly a worldwide effect upon climate. That in East Africa even a small change may have a large result has been pointed out by Walter (1938) who says: " small changes of pressure which would pass unnoticed in temperate regions become highly significant in their effect on air movements which are often of quite unexpected dimensions and directions."

As to the continuity of the eruptions, it clearly cannot be shown that continuity was maintained from year to year by successive eruptions. It is nevertheless clear that they did occur in three main phases of considerable violence, and it seems reasonable to assume that the total of these periods was only a fraction of Pleistocene time.

It has, however, to be remembered that it is only the finer material cast into the upper atmosphere which has any great climatic effect and that therefore the ashes and tuffs now to be seen can only be used as evidence for the extent and continuity of the eruptions. It is also

likely that the intensity of the climatic effect depends more upon the scale of the individual explosions than upon the number of the volcanoes, though cumulative effect must be taken into account.

It seems clear that the periods of volcanic activity in both east and west rifts was in general associated with, and apparently initiated by, earth-movement. Thus the disturbance of the Miocene peneplain during the Pliocene was accompanied and succeeded by extensive volcanics lasting into the Lower Pleistocene. Similarly the subsequent major periods of movement at the end of the Lower and Middle Pleistocene were followed by the volcanics already described. Unfortunately it is not possible to show how rapidly these volcanic phases attained to their maxima. In the diagram Text-fig. 2 it has been assumed that this occurred rapidly with a subsequent gradual decline.



TEXT-FIG. 2.—Idealized diagram of the suggested relationship between earth movement, volcanicity, and pluvials in East Africa.

Note: The stippled areas represent pluvial fluctuation as shown by the rise and fall of the lake levels.

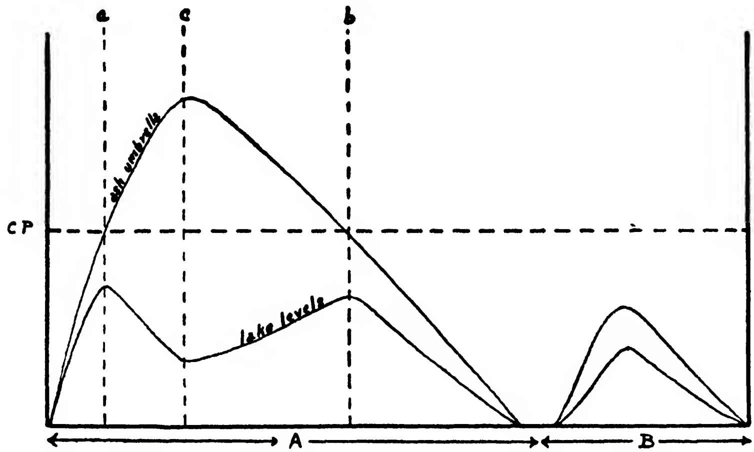
Whether this be a true picture or not, the fact remains that there appear to have been three major periods of movement, volcanics and pluviation which were broadly coincident, the pluvials being the " First Pluvial " (of Wayland) and the " Kamasian " and " Gamblian " pluvials (of Leakey). The suggested interconnection of these events is shown idealized in Text-fig. 2.

Text-fig. 3 shows diagrammatically the suggested relation of the volcanic ash in the high atmosphere to the lake levels. The progressive ejection of volcanic dust into the upper atmosphere forms an anti-radiation umbrella and thus reduces evaporation with a consequent rise of the lake levels. At first this will be a local condition, but with sufficient length of time and the extension of the effect over a wider area, not only will the normal local cycle of evaporation-precipitation be upset but a reduced precipitation arising from diminished input of

moist air from regions beyond East Africa, will cause a fall of the lake levels at the maximum of the dust umbrella.

If the condition of the dust umbrella were to remain constant at any stage an equivalent constant lake level would be established in each basin. Since, however, the volcanicity is but a phase, it is clear that one of two situations must arise. Either the volcanicity is of sufficient areal extent and duration to pass the critical point for the disturbance of the precipitation-evaporation cycle, or it falls short of this point and has a purely local effect.

In the first case the lake levels would show twin maxima for a single



TEXT-FIG. 3.—A = Double maxima pluvial. B = Single maximum wet phase in which ash umbrella fails to pass CP. CP = Critical point for disturbance of precipitation-evaporation equilibrium. a, b = Maxima of lake levels coincident with ash umbrella passing CP. c = Maximum of ash umbrella above CP coincides with minimum of lake level between maxima *a* and *b*.

volcanic phase, each maximum being at the point where the ash-umbrella effect passes the critical point for precipitation-evaporation equilibrium (Text-fig. 3, " A ").

In the second case the lake levels would show a rise and fall related only to the reduced evaporation, since the ash-umbrella effect would presumably not be great enough to affect pressure over the East African region as a whole sufficiently to disturb the input of moisture derived from the distant ocean (Text-fig. 3, " B ").

In this way major volcanic episodes would account for the twin maxima of the major pluvials, while minor episodes would account for high lake-level phases with a single maximum, both effects being provided without the necessity of invoking variations in solar radiation.

The Effect of Volcanicity on World Climate

In considering the possible effect of volcanicity on world climate it has to be remembered that the amplitude of this factor depends upon the cumulative products of all volcanic areas of the world, of which East Africa is but a single example. Thus, although the Middle Pleistocene was probably in East Africa the period of greatest activity, the effect on world climate will have depended upon the degree of synchronism between the active phases of all volcanic areas.

During the Pleistocene there were episodes of explosive volcanicity comparable to, or greater than, that of East Africa in the Andes, East Indies, New Zealand, and throughout the island areas of the Pacific, besides other more isolated centres. Unfortunately it has not yet been possible to assign the majority of these to specific periods within the Pleistocene, nor can they be discussed in detail here. It is, however, noteworthy that in the case of certain volcanoes in Java activity has been divided by Van Bemmelen (1943) into Lower, Middle, and Upper Pleistocene phases. He also provides a potential " yard-stick " by which to judge the frequency of eruptions within an active area. He shows that during the hundred years 1841–1941 there were 1,626 eruptions in the East Indies alone, yet the present is not considered to be a period of active volcanicity. Even though the greater number of these eruptions were quite minor events, this record gives some idea of the much greater number of eruptions to be expected annually over the whole world's surface during an active volcanic period such as the Pleistocene. If only one eruption of this potential number every two or three years was on the scale of Tomboro 1815, Krakatoa 1883, Katmai 1912, or the Chilean-Argentine Andes 1921, each of which gave rise to subsequent cooling of the world's climate, a reduced temperature of equivalent or greater degree would be maintained. A similar reduction of temperature would also be attained by the cumulative effect of lesser eruptions, as in particular that of Ascama in Japan in 1783 which, augmented by the Skaptar Jokull of Iceland 1783 and Vesuvius 1785, gave rise to the cool years 1784–86.

It will be seen in the second part of this communication that orogeny may well have played an equal or even greater part in varying world climate. Though it is not possible conclusively to demonstrate the relative importance of uplift and volcanicity as factors in the initiation of glacial or pluvial conditions, it seems likely that the volcanic factor exerts its greatest effect in equatorial regions (Brooks, 1926). At the same time, given the conditions consequent upon regional uplift it is probable that an explosive volcanic phase would act as a " trigger mechanism " to " set off " climatic changes of sufficient scale to effect glaciation.

PART II

The Cause of the Ice Age and the essential Rhythm of the Pleistocene

By T. T. Paterson

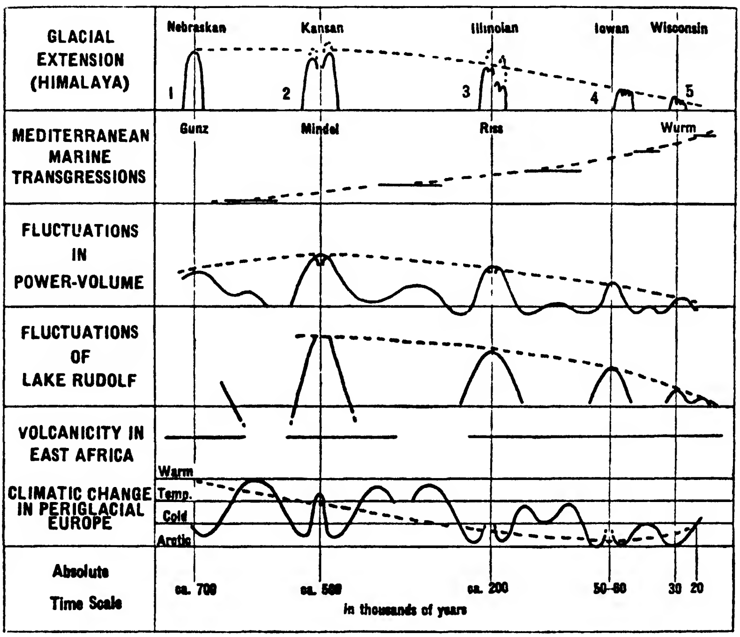
A system of Pleistocene correlation, developed from a purely stratigraphical approach, has shown the coincidence of widespread tectonic activity and glaciation and, in the tropics, the synchroneity of phases of crustal re-adjustment and major pluvial periods (Paterson, 1940, 1941). Hence it was assumed that Brooks's general theory on the effect of the redistribution of land masses in high latitudes would account for glaciation. But two items in the Quaternary story were inexplicable on this theory alone, the bifid character of each of the five glacial stages, and the generally colder and drier conditions at the end of the Pleistocene, the botanists' single glaciation. The second could not be explained by any one theory extant, but in the papers referred to the first was attributed to positive fluctuation in solar radiation, applying Simpson's admirable theory to each glacial stage.

Since that time, during odd moments of quiet in an otherwise explosive service career, it became more apparent to the writer that there was no need to postulate any extra-terrestrial phenomenon, and a conclusion was reached based on the geographical theory of Brooks, the meteorological theory of Paschinger, and the volcanic of Humphries, a combination of which, as Brooks long ago said, may account for most of the observed facts. All these theories are integrally associated, given relative synchronism of great geographic change and volcanicity. It was most satisfactory therefore to find an old friend and colleague arriving independently at a concordant conclusion on the intimate relationship of orogeny, volcanicity, and pluviation in a more intensely studied though smaller field.

The Pleistocene succession can be expressed in the accompanying series of curves, Text-fig. 4. Of the five glacial stages the first two were the greatest, the last three being progressively smaller, and their interglacial stages as well. The shortness of the fourth interglacial period, and its cool climate (see curve of climatic change), masks its essential interglacial character, especially in the sub-montane regions ; hence, in southern Germany, Penck and Brückner naturally assumed the two advances of the fifth glaciation to be but sub-stages of the fourth. Elsewhere in Europe, Asia, and America the separation is clear. Each stage of earth-movement, from the second onwards, was also progressively less intense, and was accompanied by recovery fluctuation in power-volume in the earlier portion of the inter-movement, or inter-glacial period.

Interglacial sea-levels were also correspondingly and progressively

of less extent : the series for the Mediterranean is given as being best known. It is debatable whether these marine transgressions are wholly eustatic, the result of melting of ice sheets. The progressive decrease in amplitude agrees remarkably well with the glacial cycle, but since the latter is closely related to crustal movements it follows that these fluctuations of marine levels may be, partly at the very least, epeirogenic phenomena in themselves. It is apparent that not even with complete melting of the present polar ice caps could the high Pleistocene marine levels be attained. It is suggested that these levels are related to



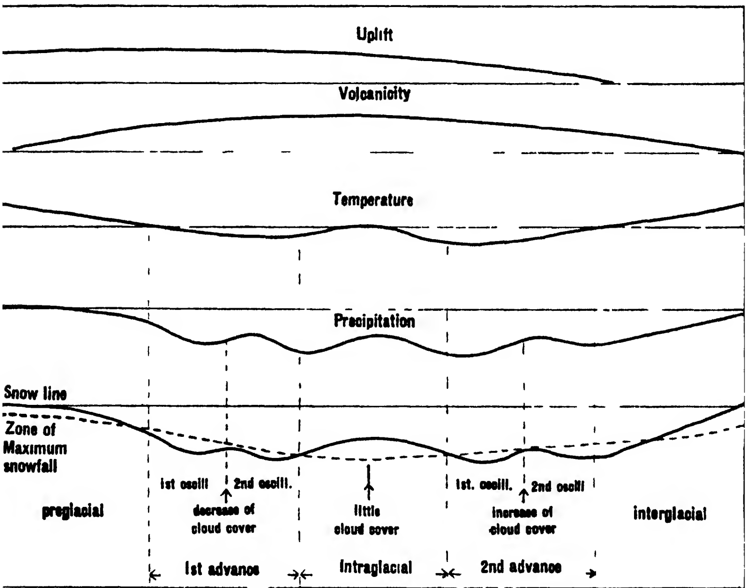
TEXT-FIG. 4.—Comparative table of Pleistocene events.

epeirogenic movements of the oceanic floor closely associated with continental upheaval. There is some positive indication of this in the submarine topography of the Indian Ocean (see John Murray Expedition Reports), and in the late submarine canyons cutting the continental shelf.

Already, in the papers cited, it had been tacitly assumed that East African lake levels were representations of pluvial periods, and the sequence for Lake Rudolf, as being the most complete, was taken from Dr. Fuchs's work. To it is here added a representation of the extension in time of the African volcanicity which he describes. Geologically

contemporaneous stages of volcanicity elsewhere show activity of some consequence resulting in fair thicknesses of ash on the floors of the Atlantic and Indian Oceans.

We are only now beginning to appreciate how vast were the crustal deformations of early Pleistocene time, and that they were sufficient to produce those changes of land and sea which Brooks demanded to account for glaciation. It can be shown, for instance, that a large part of the Scandinavian and Canadian Shields have undergone epeirogenic uplift in relation to sea level, of some thousands of feet in Plio-Pleistocene times. Given the additional lowering of temperature



TEXT-FIG. 5.—Diagram indicating the origin of the bifid character of glacial advance in high latitudes by the application of Simpson's and Paschinger's theories.

arising from explosive volcanicity, and the cycle of fluctuating snowline level according to Paschinger, the phenomena of the Pleistocene can be explained without resort to doubtful estimates of the effect of variation in solar radiation, from which estimates time scales, varying according to the factors and data chosen by different calculators, have been developed. An absolute time scale based on measurements of uranium disintegration is appended; it appears to agree with the most comprehensive of the American estimates based on decomposition of soils and such like.

An application of Simpson's and Paschinger's theories can account

for the bifid character of glacial advance in high latitudes (Text-fig. 5). In the pre-glacial condition the snowline is above the zone of maximum snowfall, precluding the formation of extensive glaciers. On uplift and shifting of the polar front, the snowline descends, and even though the zone of maximum snowfall also goes down, ultimately the snowline is lower, glaciation ensues, and is cumulative (Brooks). The climatic belts shift equatorially, and there a pluvial period commences (see Part I for local increase through local volcanicity). Precipitation does not immediately decrease with fall in temperature owing to the conservation of oceanic heat but, as evaporation begins to fall off, cloud cover is reduced thus exposing the earth's surface to more solar radiation. The ice front will oscillate. With continuing fall of temperature and the loss of oceanic heat through floating ice the supply of snow to the ice sheets finally decreases considerably. The ice-front " retreats " and the snowline returns above the zone of maximum snowfall.

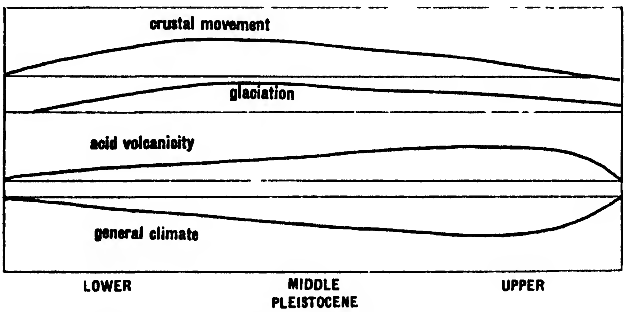
By this time the maximum of epeirogenic movement has been passed and though offset by isostatic recovery from ice load, the height of land is not so great as during the peak of glaciation. A more equable climate results, assisted by the thinness of cloud cover at the minimum of evaporation. As volcanicity dies away (the maximum of volcanicity tends to succeed that of crustal deformation), temperature rises, evaporation and precipitation increase, and the ice-sheet re-forms (Simpson). But again cloud cover develops, reducing evaporation, and the ice oscillates, recovery also being retarded by the coolness of the oceans ; the snowline finally retreats above the zone of maximum snowfall and interglacial conditions are attained.

We have thus in one glacial stage two advances of the ice-sheet and one, warmer, intra-glacial stage. Each advance is subject to oscillation, and since the effect of uplift is greater during the first advance, the moraines representing each oscillation will be progressively higher or closer to the centre, which is the condition found by the writer in the Himalaya in respect of at least the last three glaciations. In equatorial regions where the extremes of seasonal climate are not great, the snowline and zone of maximum snowfall are relatively close, and therefore ice advances and oscillations are obscured (but see Part I for doublet of pluvial periods).

The relationship of general climatic change to acid volcanicity is direct. The climatic minimum of the botanists occurs in the Upper Pleistocene during which, in East Africa at least, the discharge of ash was more or less continuous, with a maximum at the time of the Naivasha rifting. This is contemporaneous with the period of dryness during which the great aeolian deposits of China, India, and south-east Asia were formed. Nevertheless despite this all-round lowering of

temperature the glacial rhythm persisted and was coincident with stages of earth-movement. Hence the conclusion that it is most probable that glaciation was essentially the result of crustal deformation leading to uplift in relation to sea-level, secondarily augmented by the effects of accompanying volcanicity, whereas the general lowering of Pleistocene temperature to a minimum in the later part is essentially the result of volcanicity rhythmically amplified by crustal movement.

Summarizing—the phenomena of the Pleistocene are fundamentally rhythmic in character, and these rhythms can be reduced to one cycle of widespread terrestrial catastrophe with a maximum of amplitude at the beginning of the Middle Pleistocene (Text-fig. 6). Glaciation is basically the result of epeirogenic alteration of relative heights and



TEXT-FIG. 6.—Diagram representing the rhythmic fluctuations of Pleistocene phenomena reduced to a single major cycle.

levels of land and sea, perhaps through collapse of the oceanic floor, and is augmented by genetically related volcanicity (applying modifications of the theories of Brooks, Simpson, Paschinger, and Humphries). The discharge of acid volcanics reached a maximum after that of crustal movement and brought about the late Pleistocene climatic minimum.

Such a relationship of great deformation and glaciation is also found for those periods of epeirogenic and tectonic activity which ushered in geological epochs of the past. From which we may surmise the world has just witnessed the commencement of a new epoch during which the genus *Homo*, brought into being during this catastrophe, will no doubt find time to flourish, to elaborate, and finally to extinguish itself.

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Notes on some Permian Rugose Corals from Timor

By H. C. Wang (Sedgwick Museum)

(PLATE IX)

THE Permian corals of Timor are of particular value on account of their excellent state of preservation which permits of close study of the skeletal structures. The works of Gerth, Koker, and Schindewolf have added much to our knowledge in this respect. In the course of my investigation on the rugose corals as a whole, I have studied a part of the Timor material in the British Museum (Natural History), upon which this present article is based, and I am grateful to the Keeper of the Department of Geology, and to Dr. H. D. Thomas for the loan of specimens, and for the privilege of cutting them in the Museum. Dr. O. M. B. Bulman and Dr. Thomas both kindly read the manuscript. To Professor W. B. R. King and Mr. A. G. Brighton I am indebted for facilities for study in the Sedgwick Museum.

The specimens here considered are all solitary corals referable to the family Plerophyllidae of the suborder Caniniacea. They are characterized by a special kind of skeleton which is markedly lamellar or layered and is composed of slender fibre-fascicles that may be disposed in various directions but never form well-defined trabeculae. I have called this kind of skeleton fibro-lamellar. It should be noted that this sort of skeleton is not confined to the Permian solitary forms but occurs in colonial forms and in Carboniferous corals as well. Koker (1924) and Hill (1937) both drew attention to this special structure but both sought to explain it in terms of central trabeculae and lateral dilated tissue. Schindewolf (1942) was the first to point out that trabeculae do not exist in this group of corals and suggested the rather ambiguous term " diffustrabecula ".

The following is a list of species identified during my work on the Timor material. My views on the systematics of the various genera will be given in my forthcoming revision of the Zoantharia Rugosa as a whole, and only those of special interest are described and discussed here.

(*a*) Soempek, Timor.

Lytvelasma cainodon (de Koninck)
Amplexicarina abichi (Waagen and Wentzel)
Timorphyllum wanneri Gerth
T. complicatum sp. nov.
Lophophyllidium wichmanni (Gerth)
L. wichmanni var. *elongatum* var. nov.
Verbeekiella tubulosa Gerth
V. australe (Beyrich)

(*b*) Neoepantoekak, Timor.
Timorphyllum wanneri variabilis Gerth
Tachyelasma timorense (Gerth)
Pleramplexus similis Schindewolf

(*c*) Toenioen Eno, Timor.
Verbeekiella australe (Beyrich)
Prosmilia cyathophylloides (Gerth)
Tachyelasma timorense (Gerth)

(*d*) Basleo, Timor.
Timorphyllum wanneri (Gerth).

FAMILY : *PLEROPHYLLIDAE*

Solitary corals, skeleton fibro-lamellar, septa composed of slender fibre-fascicles, wall thick, dissepiments absent except in specialized forms. Lower Carboniferous—Permian.

Remarks.—Two distinct morphological groups never apparently grading into each other are recognizable in the Permian and Carboniferous solitary corals referrable to the family Plerophyllidae. In the first group the axial structure, either in the form of a columella or a complex axial column, is the prominent feature and is more or less connected with the counter septum. The cardinal septum is always the shortest, and all the other septa are roughly radial and never conspicuously differentiated in size. This forms my subfamily Lophophyllidinae. The second group, which constitutes the subfamily Plerophyllinae, is characterized by a marked differentiation (rhopaloid) of some of the major septa and the consequent conspicuous bilateral symmetry.

SUBFAMILY : *LOPHOPHYLLIDINAE* NOV. SUBFAMILY

Solitary corals, axial structure mostly prominent, fibre-fascicles in the septa grouped in various ways in advanced forms.
Upper Carboniferous—Permian.

Genus : **Timorphyllum** Gerth, 1921

Genotype.—*Timorphyllum wanneri* Gerth, 1921, Permian, Timor.

Diagnosis.—Trochoid, ceratoid or subcylindrical corallum, septa thin, composed of fibre-fascicles perpendicular to the septal plane, counter septum conspicuously larger and longer, minor septa short, tabulae numerous and domed, no dissepiments.
Upper Carboniferous—Permian.

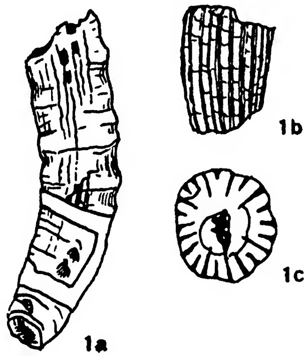
Remarks.—The distinguishing characters of this genus are the simple structure of the septa and the " lamellar " kind of columella

formed by the counter septum. The columella may be seemingly discontinuous from the counter septum in late stages. I have included *Soshkineophyllum* Grabau as a synonym which differs from *Timorphyllum* only in the more irregular and numerous tabulae and in the occasional slight dilatation of some of the major septa. Jeffords recently established the new genus *Stereostylus* (genotype *S. lenis* Jeffords, 1947), which I regard as a synonym of *Timorphyllum.*

Timorphyllum complicatum sp. nov.
(Pl. IX, fig. 2*a–b*, 3–4, Text-fig. 1)

Holotype.—BM R 33078. Permian, Soempek, Timor.

Diagnosis.—Curved ceratoid to subcylindrical *Timorphyllum* with the counter-septum twisted at the axis to form a complex columella, and without minor septa.



TEXT-FIG. 1*a.*—*Timorphyllum complicatum* sp. nov. × 1. Holotype, BM R 33078.
TEXT-FIG. 1*b–c.*—The same × 1. Paratype BM R 33199.

Description.—The holotype is curved subcylindrical in form and attains a diameter of 12 mm. at the distal end. Another specimen is elongated ceratoid and a little larger in size. Faint constrictions and septal grooves are marked on the surface. There are three to four major septa in the cardinal, and six in the counter, sectors including the counter-lateral ; and minor septa are absent. In the proximal portion the septa are slightly dilated. A cardinal fossula with a very short cardinal septum is prominent. The wall is markedly thick and is composed of parallel fibre-fascicles directed inward, which abut against the wedge-shaped septal ends. The median dark band representing the axis of calcification, the slender fibre-fascicles perpendicular to the septal plane, and the layered structure of the skeleton in general are very well shown in the transverse section (33078 *c–d,*

Pl. IX, fig. 4). The fibre-fascicles are throughout horizontally disposed in the wall and in the septa. In the proximal section the counter septum extends to the axis and folds upon itself in the form of a loop (Pl. IX, fig. 3). Subsequently the twisting of the loop becomes so complicated that separate branches of axes of calcification are developed (Pl. IX, fig. 4).

Remarks.—Apart from the twisted nature of the columella, this species bears a close resemblance to *T. wanneri*, the genotype. As far as can be made out from the figures, *Lophophyllum acostatum* Soshkina 1928 (= *Sinophyllum acostatum* Soshkina, Dobrolyubova and Porpiriev 1941) from the Urals and *Lophophyllum kayseri* Huang (1932, pp. 24, pl. ii, fig. 3) seem to bear some resemblance to our form.

Genus : **Lophophyllidium** Grabau 1928

Genotype.—*Cyathaxonia proliferum* McChesney 1860, Upper Carboniferous, Illinois, U.S.A.

Diagnosis.—Curved ceratoid corallum, septa thick, composed of fibre-fascicles perpendicular to the septal plane in young stage but variously disposed in adult stage, minor septa short, columella composed of long fibre-fascicles, tabulae domed, no dissepiments.

Upper Carboniferous—Permian.

Remarks.—In 1928 Grabau proposed the name *Lophophyllidium* with *Cyathaxonia proliferum* as its genotype and at the same time *Sinophyllum* with the genotype *Lophophyllum pendulum*. The validity of *Sinophyllum* as a genus has already been questioned by Huang (1932, p. 23) who has examined and figured *C. proliferum* from America and considered it congeneric with *Sinophyllum pendulum*. Through the kindness of Dr. S. Smith I have studied some thin sections of *C. proliferum* from Illinois, which show exactly the same complex axial columella and lateral fibre-fascicles as in *Sinophyllum pendulum*. In addition to *Sinophyllum* I have also included *Malonophyllum* Okulitch and Albritton (1937, genotype *M. texanum*, from Permian of Texas) and *Leonardophyllum* Moore and Jeffords (1941, genotype *L. acus* from Permian, Kansas) as synonyms of *Lophophyllidium*. Incidentally, I may point out that the columella of *Lophophyllidium* (and therefore *Sinophyllum*) is always connected with the counter septum and with it only ; it is not formed by the association of dilated axial ends of other major septa, as stated by Hill (1937, p. 64).

Lophophyllidium wichmanni (Rothpletz)

Clisiophyllum wichmanni Rothpletz 1892, p. 71, pl. xii, fig. 17–18, 30).

Carcinophyllum wichmanni, Gerth 1921, p. 19, pl. iii, fig. 1–4.

Material examined.—BM R 32868, 33077, 33079, 33198.

Diagnosis.—Trochoid to seratoid *Lophophyllidium* with large columella composed of a median row and numerous outer radiating rows of fibre-fascicles, inner ends of septa rhopaloid and in contact, minor septa stout and short, contiguous with the major septa in the peripheral zone, tabulae weak and domed.

Lophophyllidium wichmanni var. *elongatum* var. nov.

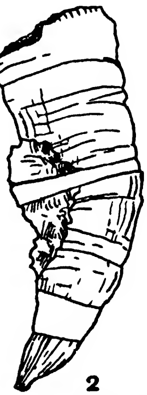
(Pl. IX, fig. 8, 9 *a–c*, Text-fig. 2)

Holotype.—BM R 32988, Permian, Soempek, Timor.

Material examined.—BM R 32988, 32989.

Diagnosis.—Large elongate ceratoid *Lophophyllidium wichmanni* with complex septal structure near the periphery.

Description.—The corallum is elongated ceratoid and slightly curved, 56 mm. long and around 15 mm. in diameter at the distal end. Growth lines and wrinkles are marked on the surface. In the proximal portion the columella consists of a median dark band and long fibre-fascicles on both sides, much comparable with that of the Lower Carboniferous *Koninckophyllum* group. In the distal section the median portion becomes surrounded by numerous short radiating bars with their own calcification axes, and the columella is structurally no longer confluent with the counter septum. A kind of inner wall is formed by the connected rhopaloid inner ends of the major septa. The minor septa are short and contratingent against the majors. In the peripheral region the fibre-fascicles are grouped in various ways. There may be either numerous crowded short and open fascicles in one septum (Pl. IX, fig. 8), or the septa may split up into longitudinal segments with their own calcification axes (Pl. IX, fig. 9*c*).



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TEXT-FIG. 2.—*Lophophyllidium wichmanni* var. *elongatum* var. nov. × 1. Holotype, BM R 32988.

Remarks.—*Lophophyllidium wichmanni* differs from other species in its well developed minor septa and complex columella, and its incomplete domed tabulae. In the rhopaloid inner ends of the septa it much resembles the genotype. Our new variety is distinguished from the typical species in its size and elongated shape of the corallum and the complex septal structures. The splitting up of the peripheral parts of the septa as seen in our specimen (Pl. IX, fig. 9*c*) may be

compared with *Lophophyllum amygdalophylloides* Huang (1932, pl. ii, fig. 12*a*).

Genus : **Verbeekiella** Gerth 1921

Genotype.—*Verbeekia permica* Penecke (= *Clisiophyllum australe* Beyrich), 1908, Permian, Australia.

Diagnosis.—Cornute corallum, septa thick, composed of long fibre-fascicles perpendicular to the septal plane, axial column large and open, numerous incomplete domed tabulae, no dissepiments. Permian.

Remarks.—The essential characters of *Verbeekiella* are its generally dilated skeletal structure and the large open axial column which is isolated from the counter septum in an early stage. In the genotype, *V. australe*, the axial column is " favositoid " and is independent of the counter septum from a very early stage, but the mode of its formation is not clearly understood. *V. rothpletzi* and *V. tubulosa* have an axial column composed of anastomosing septal lamellae and tabellae. It seems probable that *Lophophyllidium cristatum* (Gerth, *Carcinophyllum cristatum*) may better be merged with *L. rothpletzi.*

In *Verbeekiella* the fibre-fascicles are all subparallel and never grouped or specially arranged. The minor septa are rudimentary or wanting. It is evident that *Verbeekiella* cannot have arisen from *Lophophyllidium* which has complicated septal structures and well developed minor septa. I am inclined to think that *Timorphyllum* might be ancestral to *Verbeekiella*, especially as a new species of the latter possessing a complex axial structure has been found.

Verbeekiella australe (Beyrich) (Pl. IX, fig. 5)

Verbeekiella australe, Gerth 1921, p. 84, pl. i, fig. 14, pl. ii, fig. 4–5, pl. iii, fig. 12–13.

Material examined.—BM R 32579, 33129.

Diagnosis.—Strongly curved cornute *Verbeekiella* with marked wrinkles, a wide open favositoid axial column, septa dilated and entirely contiguous in early stages, but free in the counter sectors in the adult stage, minor septa absent or rudimentary, fibre-fascicles in the septa horizontally disposed and perpendicular to the septal plane.

Remarks.—The axial column is composed of a central " favositoid " part without skeletal dilatation, surrounded by stout contiguous radiating bars with long fibre-fascicles and clear axes of calcification. Except in the proximal portion, where the counter septum still shows a structural continuity with the column, the latter is sharply demarcated from the surrounding septa. It seems that in the living condition the

polyp was anchored in the central tube (favositoid portion) and the deep circular pit around the column, and the discordant fibre-fascicles in the septa and the column were secreted by the opposite surfaces of the polypal part in the pit. As revealed by the longitudinal section, the fibre-fascicles in the septa and in the wall, as well as in the axial column, are exactly horizontal and nowhere show any secondary grouping.

Verbeekiella tubulosa Gerth (Pl. IX, fig. 6)

Verbeekiella tubulosa Gerth 1921, p. 86, pl. ii, fig. 6, pl. iii, fig. 16–18.

Material examined.—BM R 32918, 33109.

Diagnosis.—Small cornute *Verbeekiella* with open anastomosing axial column, septa dilated and contiguous in early stages, fibre-fascicles in the axial part of septa directed upward, those in the lateral parts remaining horizontal.

Remarks.—In external form and in the immense dilatation of the skeleton in early stages, *Verbeekiella tubulosa* resembles closely *V. australe*. Apart from the anastomosing axial column it differs from the latter in the disposition of fibre-fascicles in the middle part of the septa. Fig. 6 (Pl. IX) represents the transverse section of one septum, the median portion revealing the upwardly inclined, and the lateral parts the horizontal fibre-fascicles. That the median portion is not formed by successive sections of trabeculae, as in most trabeculate corals, is proved by the longitudinal and tangential section, where the inclined fibre-fascicles in the middle pass directly into the lateral horizontal parts. It seems that in the living condition the median portion of the septal invagination of the polyp had always kept a little higher than the lateral parts, so that a median ridge was formed of the upwardly inclined fascicles secreted in this particular central zone, while the lateral parts at the same level were formed a little later. This explanation is further supported by the extreme calical section, in which the septa are thin and have the same structure as the median portion of the lower, dilated septa.

Genus : **Plerophyllum** Hinde 1890

Genotype.—Plerophyllum australe Hinde 1890, Permian, Australia.

Diagnosis.—Curved ceratoid corallum, C, 2A, 2KL, sometimes also K, larger; septa composed of fibre-fascicles grouped into arched patches in the septal plane, tabulae numerous and domed, no dissepiments, wall may be degenerate. Permian.

Subgenus : **Pleramplexus** Schindewolf 1940

Genotype.—Pleramplexus similis Schindewolf 1940 Permian, Timor.

Diagnosis.—Plerophyllum with shortened and weakly rhopaloid septa composed of fibre-fascicles grouped into arched patches and with flat, nearly complete tabulae.

Remarks.—Pleramplexus represents the amplexoid trend of *Plerophyllum*. Schindewolf founded this subgenus on *P. similis*, which may prove to be conspecific with *Caninia arundinacea* (Lonsdale) (Koker 1924, p. 12, pl. i, fig. 7–7*a*, pl. iii, fig. 1–2, Text-fig. 9–9*a*). But as that species was not adequately figured by Lonsdale, and as various forms not necessarily belonging to one species have subsequently been loosely assigned to it, I have thought it advisable for the moment to hold *Caninia arundinacea* in suspension.

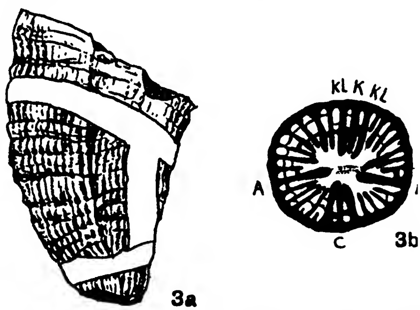
Pleramplexus similis Schindewolf (Pl. IX, fig. 1*a–b*, Text-fig. 3*a–b*)

Caninia arundinacea, Koker 1924, Permian, Timor.

Pleramplexus similis Schindewolf 1940, Permian, Timor.

Material examined.—BM R 32738.

Diagnosis.—Large trochoid *Pleramplexus*, C. 2A, K and the first



TEXT-FIG. 3.—*Pleramplexus similis* Schindewolf. BM R 32738.
(*a*) Lateral view of corallum × 1.
(*b*) Proximal transverse section × 1·5.

pair of cardinal laterals larger in early stages, C reduced and all the major septa retreat from the axis in late stages, minor septa well developed, tabulae flat and complete.

Description.—Corallum curved trochoid, 28 mm. thick at the distal end and over 35 mm. long. Septal grooves and wrinkles are well marked. In a proximal section measuring 12 mm., C, 2A, K, 2KL and the first pair of the cardinal laterals are conspicuously larger. In the distal section all the major septa are reduced to half the radius of the corallum. The counter-septum remains the largest, the cardinal is aborted, with a prominent cardinal fossula, all the other major

septa are subequal in size and weakly rhopaloid. The arched patches of fibre-fascicles along the septal plane are exactly like those observed in *Plerophyllum* and *Tachyelasma.* Minor septa are well developed. The tabulae are fairly distant, flat in the central and inclined in the peripheral region.

Genus : **Lytvelasma** Soshkina 1925

Genotype.—Lytvelasma assymmetricum Soshkina 1925, Permian, Urals.

Diagnosis.—Turbinate or ceratoid corallum, septa thick, entirely contiguous, fibre-fascicles perpendicular to the septal plane, major septa reaching the axis, minor absent or rudimentary, a cardinal fossula is present, tabulae suppressed.

Remarks.—Lytvelasma shows neither trace of axial structure nor differentiation of the septa, and it is doubtful whether it should be referred to Plerophyllidae or to Caninidae. The distinguishing features are the extremely simple septal structure consisting of parallel fibres and the immense dilatation of septa. In 1937 Hill established the genus *Euryphyllum* (genotype *E. reidi* Hill 1937) and described several species. *Euryphyllum* is characterized by the dilatation of septa in the peripheral and the axial zone and the presence of a prominent cardinal fossula. In 1942 she figured as *E. reidi* a specimen from western Australia, which seems to me to be a *Lytvelasma.*

Lytvelasma cainodon (de Koninck) (Pl. IX, fig. 7, Text-fig. 4)

Zaphrentis cainodon, Koker 1924 (pars), p. 9, pl. i, fig. 1–2, pl. iii, fig. 1–2.

Z. triadedum Koker 1924, p. 10, pl. ii, fig. 1–1*a.*

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TEXT-FIG. 4.—*Lytvelasma cainidon* (de Koninck) × 1. BM R 33197.

Material examined.—32126, 33197

Diagnosis.—Elongated ceratoid *Lytvelasma* with narrow cardinal fossula, a narrow strip of open interseptal loculi near the periphery, and without minor septa.

Description.—This species is represented by two specimens, one 28 mm. high and 15 mm. thick, the other 35 mm. high and 11 mm. thick at the distal end. Epitheca is absent and the septa stand in high relief on the surface. The calice is flat and slightly arched and with a very narrow cardinal fossula. The septa are roughly radial, reach the axis, and are contiguously dilated throughout their length except in the extreme peripheral part, where open interseptal loculi are present.

The cardinal fossula is very narrow and the cardinal septum conspicuously thinner than the other septa. The fibre-fascicles in the septa, as well revealed in the transverse, longitudinal, and tangential sections, are exactly parallel and horizontal in position.

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EXPLANATION OF PLATE

FIG. 1.—*Pleramplexus similis* Schindewolf, × 2. BM R 32738 *a–b*. Neoepantok, Timor.
(*a*) Transverse section.
(*b*) Longitudinal section.

FIG. 2.—*Timorphyllum complicatum* sp. nov. × 2. Holotype BM R 33078 *a–b*. Soempek, Timor.
(*a*) Proximal transverse section.
(*b*) Distal transverse section.

FIG. 3.—The same × 15. BM R 33078*a*, showing the folding of the extended counter septum in the axial region.

FIG. 4.—The same × 15. BM R 33078*b*, showing the complicated twisted structure of the columella.

FIG. 5.—*Verbeekiella australe* (Beyrich) × 2. BM R 32579. Toenioen Eno, Timor, showing the favositoid axial column and the parallel fibre-fascicles in the septa.

FIG. 6.—*Verbeekiella tubulosa* Gerth × 15. BM R 33109*b*. Soempek, Timor, showing one septum with the median portion of upwardly inclined fibre-fascicles and the lateral parts of horizontal fibre-fascicles.

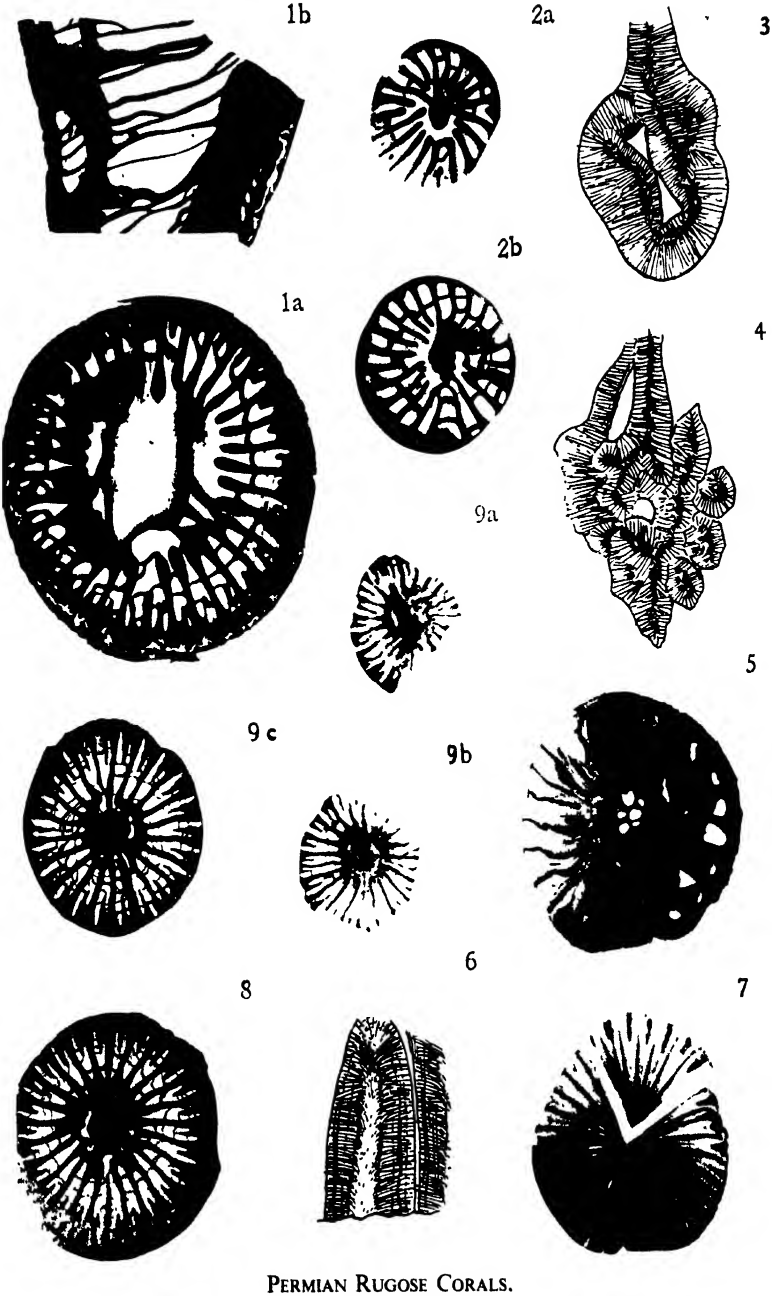
FIG. 7.—*Lytvelasma cainodon* (de Koninck) × 2. BM R 33197*a*. Soempek, Timor, showing the simple septal structure and the narrow cardinal fossula.

FIG. 8.—*Lophophyllidium wichmanni* (Gerth) var. *elongatum* var. nov. × 2. BM R 32989. Soempek, Timor, showing the complex columella and the numerous fibre-fascicles variously grouped in the peripheral region.

FIG. 9.—The same × 2. Holotype BM R 32988 *a–c*. Soempek, Timor.

a–b. — Proximal transverse sections showing the complex columella.

(*c*) Distal transverse section showing the splitting up of the peripheral portion of the septa into longitudinal segments with their own calcification axes.



PERMIAN RUGOSE CORALS.

Tetradella complicata (Salter) and some Caradoc species of the Genus

By J. C. Harper (University of Liverpool)

(PLATE X)

IN this country the best known species of *Tetradella* is *T. complicata* (Salter), a form which is usually regarded as typical of Caradoc rocks and has been widely quoted in faunal lists as such. It happens, however, that this species was originally described as *Beyrichia complicata*, by Salter (Phillips and Salter, 1848, p. 352, pl. 8, fig. 16) from the Llandeilo Beds of Llan Mill, near Narberth, and it is extremely unlikely that it ever occurs in Caradoc beds. This confusion has no doubt arisen from the inaccuracies in Salter's original figure, the briefness of the accompanying description and the fact that McCoy figured what is obviously another species of *Tetradella* under the same name from the Caradoc Beds of Pont y Meibion (McCoy, 1851, pl. IE, fig. 3). At a later date T. R. Jones refigured *T. complicata* from Llan Mill with more accuracy than Salter and with a fuller description, but unfortunately figured under the same name a form from the Caradoc of Harnage, giving also a list of Llandeilo and Bala localities where *T. complicata* was supposed to occur (Jones, T. R., 1855, pp. 163–5, pl. vi, figs. 1–5). In addition to this figures have appeared in various textbooks and similar works of a general nature which are usually too poor for specific determination although it is obvious that in the main they cannot be referred to *Tetradella complicata* (Salter).

In this paper *Tetradella complicata* (Salter) is redescribed, and an account is given of some existing and new species of *Tetradella* from the Caradoc.

The orientation of *Tetradella*, and most other Palaezoic ostracoda, is a problem which presents many difficulties (Harper, 1940, pp. 386–9), and in the following account the somewhat arbitrary basis of the asymmetry of the free margin of the valves with relation to the dorsal margin is used, i.e., the outline of the free margin of the valves is taken as having a backward swing.

The material used in this investigation has in the main been loaned by the Sedgwick Museum, Cambridge, and the Geological Survey, and the author's thanks are due to Mr. A. G. Brighton and Dr. C. J. Stubblefield for arranging the loans and giving much useful information concerning type specimens. The author's thanks are also due to Professor W. F. Whittard for the gift of material from the Spy Wood Grit.

Tetradella complicata (Salter)

Pl. X, fig. 3

Beyrichia complicata, Salter, 1848, p. 352, pl. 8, fig. 16.
Beyrichia complicata, McCoy *ex* Salter, 1851, p. 136, pars., *non* pl. IE, fig. 3.
Beyrichia complicata, Salter, 1853, p. ii, pars.
Beyrichia complicata, Jones, 1855, p. 163, pl. 6, figs. 1–4, *non* 5.
Beyrichia complicata, Huxley and Etheridge, 1865, p. 3.
Beyrichia complicata, Salter in Ramsay, 1866, p. 295, pl. 19, fig. 9; 1881, p. 487, pl. 19, fig. 9.
Beyrichia complicata, T. R. Jones, 1870, pl. lxi, fig. 21.
Tetradella complicata, Ulrich, 1890, p. 112.
Tetradella complicata, Ulrich and Bassler, 1908, p. 306.
Tetradella complicata, Stubblefield, 1938, p. 55.

Valve surface smooth and with no general convexity. Backward swing of the carapace slight. Three main ridge-like lobes are present, separated by deep, wide, flat-bottomed sulci. A sharp ridge runs along the free margin of the valves of which the anterior and posterior lobes form part, the mid-lobe joining the marginal ridge with a slight backward curve. The surface of the valves turns down at right angles along the free margin and is slightly inset. The anterior lobe is formed by the slight dorsal widening of the marginal ridge. The mid-lobe is narrow and slightly curved, the anterior side being convex. Dorsally the lobe tends to swell out and become faintly clavate. The posterior lobe, which is formed by a slight widening of the posterior part of the marginal ridge, curves over in an anterior direction dorsally to form a loop or sometimes a wide tubercle so that the whole lobe has an appearance like a reversed comma. A branch from this lobe at right angles to, and from the middle of, the postero-ventral curve of the marginal ridge stops just before reaching the tubercle on the posterior lobe; a well defined oval pit is bounded by the two branches of the posterior lobe, the boundary being broken only by the small gap between the dorsal end of the inner branch and the tubercle on the dorsal termination of the main branch.

Internal moulds show less sharp lobes than the external surface of the valve and the marginal ridge may become indistinct and even discontinuous. The mid-lobe may appear to swell out into a tubercle dorsally and the main branch of the posterior lobe may sometimes be represented only by a sharp dorsal tubercle.

Lectosyntypes.—Stubblefield (1938, p. 35) has stated that he regards the specimens figured by Jones (1855, pl. 6, figs. 3 and 4) preserved on Geological Survey specimen 24525 as lectosyntypes, and as Salter's original specimens are not identifiable this would seem the correct course to take. However, Geological Survey specimen 24526 shows the external impression counterpart of the specimen shown in Jones' fig. 3 and this must also be regarded as a lectosyntype.

Locality and Horizon.—Llandeilo Flags of Llan Mill, near Narberth
Dimensions.—Length along hinge, 2 mm. Maximum height, 1 mm.

Remarks—The distinguishing features of this species are the flattened appearance of the valves, the comma-like shape of the main posterior lobe, and the oval pit enclosed by the two branches of the posterior lobe. Many figures referred to *T. complicata* in various textbooks and similar works cannot now be recognized as belonging to that species, but owing to inadequate drawing and lack of information about original specimens it is not possible to assign them to any particular species, e.g. Salter in Murchison, 1854, Foss. 29, fig. 7; Baily, W. H., 1875, pl. 13, figs. 3*a*, 3*b*, 3*c*.

Tetradella scripta sp. nov.

Pl. X, figs. 1, 2, 8. Text-fig. 1*a*

Beyrichia complicata, McCoy *ex* Salter, 1851, p. 136 pars., pl. IE, fig. 3.
Beyrichia complicata, Salter, 1853, p. ii pars.
Beyrichia complicata, Salter, 1873, p. 48.
Beyrichia (Tetradella) complicata, Woods, 1946, p. 380, fig. 193.

Outline almost semi-circular, with slight backward swing to carapace. Surface usually appearing smooth but in well-preserved material can be seen to be minutely tuberculate. Free margin with a continuous ridge from which the marginal portions of the lobes are separated by a deep furrow. Valve plunges at right angles from the marginal ridge to junction with other valve. Valve surface has only slight general convexity. There are three main lobes which are narrow ridges, joining ventrally but separated along most of their length by broad furrows. The anterior lobe is parallel to the marginal ridge anteriorly but approaches it more closely ventrally; it projects slightly beyond the dorsal margin and runs into the mid-lobe, just above its ventral termination, at right angles. Mid-lobe slightly curved with forward convexity and projecting slightly above the dorsal margin. This lobe crosses the ventral furrow and joins the marginal ridge almost at right angles. The posterior lobe arises at right angles to the mid-lobe just above the marginal ridge, but below the junction of the anterior lobe with the mid-lobe, a feature which is well brought out in McCoy's figure (1851, pl. IE, fig. 3). The posterior lobe runs nearly parallel to the marginal ridge, from which it is separated by the furrow, but at the dorsal margin the lobe and marginal ridge are almost in contact. About one-third of the distance to the dorsal margin a short weak ridge-like side lobe branches from the inner side of the posterior lobe. This subsidiary lobe does not reach the dorsal margin. In the internal mould the anterior lobe appears broad, with a rounded contour, but with a ridge along its summit, dropping sharply to the

furrow separating it from the mid-lobe. The mid-lobe is a sharp ridge but merges into the marginal slope ventrally. The posterior lobe has again a broad rounded contour, with a ridge along its summit, dropping sharply to the furrow on its anterior side. The low, short subsidiary ridge is seen branching from the inner side of the posterior lobe.

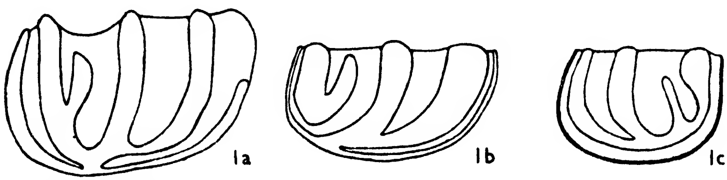
Holotype.—Geological Survey specimen 74875A, an external impression of a right valve.

Paratype.—Geological Survey specimen 74875B, an internal mould of a right valve.

Horizon and Locality.—Caradoc. Small exposure under bank by the footpath about 170 yards east of Cwms Cottage (one-third of a mile south-east of Caer Caradoc, Shropshire).

Dimensions of holotype.—Hinge length, 2·75 mm. Maximum height, 2.0 mm.

Remarks.—The specimen figured by McCoy (1851, pl. IE, fig. 3) from the Caradoc of Pont y Meibion and now in the Sedgwick Museum



TEXT-FIG. 1.—(*a*) *Tetradella scripta* sp. nov. Camera lucida sketch (× 11) of plasticene impression of holotype. Marginal ridge not preserved anteriorly.
(*b*) *Tetradella bicuneiformis* sp. nov. Camera lucida sketch (× 13) of plasticene impression of holotype.
(*c*) *Tetradella salopiensis* sp. nov. Camera lucida sketch (× 13) of plasticene impression of holotype.

(A 16696) has a similar arrangement of the lobes, although not such a robust appearance, or such a large size. It may be referred to *T. scripta* however. Other material belonging to this species has been found in Caradoc beds in fissures in the Pre-Cambrian at Dry Hill, near Church Stretton, and in Caradoc Beds along the River Dwyfach 320 yards north-east of the power house at Plas Hen near Llanystwmdwy, Caernarvonshire. In neither of these localities are the dimensions of this species as great as they are in the form from Cwms Cottage.

Tetradella bicuneiformis sp. nov.

Pl. X, figs. 4, 10. Text-fig. 1*b*

Valve surface smooth, general contour only slightly convex. Ventral margin rounded with slight backward swing to carapace. Narrow

raised rim along free margin. Surface marked with three main ridge-like lobes separated by broad furrows; the posterior lobe is bifurcate. The anterior lobe is nearly parallel to the free margin, from which it is separated by a narrow groove which widens slightly dorsally. This lobe swings back and joins the mid-lobe ventrally and the continuation of the two confluent lobes joins the marginal rim at an acute angle postero-ventrally. The mid-lobe is higher and slightly wider than the other lobes but has the same ridge-like form. The posterior lobe consists of a ridge nearly parallel to the posterior part of the border rim, from which it is separated by a groove which narrows slightly dorsally, and a sharp distinct lobe forking off at an acute angle from its ventral end and reaching three-quarters of the way to the dorsal margin. This bifurcate lobe is separated completely from the mid-lobe by the furrow on its inner side which joins the marginal groove. The internal mould, the description of which is based mainly on the paratype as that is more typical as regards the internal mould, shows a rounded slope down to the free margin; the anterior lobe has a rounded contour and runs into the general slope down to the free margin. The mid-lobe retains its ridge form whilst the posterior lobe is again rounded with a slight ridge on its summit dorsally, a very small almost tubercle-like subsidiary lobe arising from the base of the posterior lobe, the combined lobe being limited ventrally by a shallow depression which is a continuation of the furrow between the mid and posterior lobes.

Holotype.—Geological Survey specimens 75421A and 75422A. External impression and internal mould counterpart of a right valve.

Paratype.—Geological Survey specimens 75421B and 75422B. External impression and internal mould counterpart of a left valve.

Horizon.—Spy Wood Grit.

Locality.—Exposure by cart track in field south of road 400 feet west of the Post Office, Rorrington, Salop.

Dimensions of holotype.—Length of hinge 1·75 mm. Maximum height, 1.25 mm.

Remarks.—This form resembles *Tetradella scripta* sp. nov. in its marginal rim and the ridge-like appearance of the lobes, but is smaller. The posterior lobe is completely separated from the mid-lobe and its inner branch is much more developed than in *T. scripta*. The anterior lobe becomes confluent with the mid-lobe ventrally and the continuation of the two meets the marginal ridge at an acute angle instead of nearly at right angles as in *T. scripta*.

Tetradella decorata (Jones)

Beyrichia complicata var. *decorata*, Jones, 1855, p. 165, pl. vi, fig. 6.
Beyrichia complicata decorata, Ulrich and Bassler, 1908, p. 306.

This species was originally described by Jones as a variety of *Tetradella complicata* (Salter) but in view of the quite different arrangement of the lobes it seems clear that it can now be regarded as a separate species. It is characterized by its unusually wide frill, granulate surface, and row of strong marginal spines all of which are of the same order of magnitude.

Lectotype.—Geological Survey specimen 35718. An external impression from the Caradoc of Abermarchnant.

Tetradella superciliata (Reed)

Pl. X, fig. 6

Beyrichia (*Ctenobolbina?*) *superciliata*, Reed, 1910, p. 218, pl. xvii, figs. 14, 14*a*.
Beyrichia (*Tetradella*) *turnbulli*, Reed, 1910, p. 219, pl. xvii, figs. 12, 12*a*, 13, 13*a*.

Hinge straight, backward swing to carapace not marked, but accentuated by the widening of the frill posteriorly. Valves strongly convex, with lobes united ventrally into the rounded margin of the valve. Surface covered with fine tubercles, with three or four rows of fine spine bases along the free margin. Two or three much larger spine bases are set amongst them. The boundaries of the lobes are marked out by a line of tubercles or spine bases and the dorsal termination of each lobe bears a tubercle. There is a row of small tubercles just below the dorsal margin. The free margin is furnished with a moderately convex frill which becomes wider postero-ventrally. This frill shows rather irregular low radiating ridges and its external edge is finely milled. The arrangement of the lobes in this form is adequately described by Reed (1910, p. 218).

Holotype.—Sedgwick Museum A.10985 *a* and *b* (Reed, 1910, pl. xvii, figs. 14 and 14*a*).

Horizon and Locality.—Caradoc. Dufton Shales. Cutting in Alston Road, near Melmerby.

Remarks.—The forms referred by Reed (1910, p. 219, pl. xvii, figs. 12, 12*a*, 13, 13*a*) to *Tetradella turnbulli* have so many points of resemblance to *T. superciliata* in the arrangement of the lobes, fine overall granulation of the surface, the arrangement of the larger tubercles or spine bases that it does not seem possible to regard the two forms as separate species. The main point of difference lies in the possession of a spinose margin and the absence of a frill in *Tetradella turnbulli*. In the opinion of the present author the frill is absent owing to non-preservation and the spines are merely those which happen to be lying in the plane of the brim and have been preserved.

Reed's reference of *T. superciliata* to *Ctenobolbina* cannot be admitted as this form shows the four lobes typical of *Tetradella,* although its lobes have not the usual ridge-like form found in *Tetradella.* Ulrich (1890, p. 113) remarks on the similarity of the anterior part of the valves in *Ctenobolbina* and *Tetradella* and the difference in their posterior part. The presence of a frill is known in other species of *Tetradella*, e.g. *T. subquadrans* Ulrich, although Swartz (1936, p. 551) does not admit forms with a well developed frill into his Family Tetradellidae. Ulrich (1890, p. 112) states that *Tetradella* is never tumid although *T. marchica* (Krause) has somewhat tumid lobes and Swartz (1936, p. 554, explanation to pl. 81) queries its reference to *Tetradella.* Öpik has referred that species to his genus *Tallinnella* (1937, p. 24), which is characterized by a brood pouch. It may be that forms resembling *T. superciliata* (Reed) will have to be placed in *Tallinnella* if a brood pouch is identified but the rounded character of the lobes would suggest that a new genus may have to be erected for forms such as this.

Tetradella salopiensis sp. nov.

Pl. X, figs. 5, 7, 9. Text-fig. 1*c*

Outline somewhat rectangular, posterior swing but little marked. Ventral border plunging down vertically to a narrow frill with an upturned margin. Anterior lobe rather wide and flat but with a ridge on its inner side dropping sharply to the furrow ; it narrows ventrally and curves round parallel to the frill to join the ridge-like mid-lobe, the ventral end of which curves round posteriorly to join the posterior lobe, so that there is a continuous ridge running parallel to the frill.

The posterior lobe is a ridge, becoming expanded slightly dorsally. The subsidiary ridge arises from the postero-ventral part of the marginal ridge and reaches about halfway to the dorsal margin. The internal mould shows a rounded slope running down to the ventral margin, the anterior and posterior lobes being rounded and running into this slope, but they have steep slopes on their inner sides. The posterior lobe shows a dorsal tubercle and a short sharp subsidiary ridge on the inner side. The mid-lobe is a ridge running into the rounded ventral slope.

Holotype.—Geological Survey specimen 75421C and 75422C. An external impression and internal mould respectively.

Horizon and Locality.—Spy Wood Grit. Exposure by cart track in field south of road 400 feet west of the Post Office, Rorrington, Salop.

Dimensions of holotype.—Hinge length, 2·0 mm. Maximum height, 1·25 mm.

Remarks.—This form comes closer to *T. complicata* (Salter) than

the others described, but has a frill which is not seen in *T. complicata*. In addition the comma-like posterior lobe and the oval pit enclosed by it and the subsidiary lobe are not present in *T. salopiensis*. Neither does the mid-lobe have a clavate tendency dorsally. In internal moulds *T. salopiensis* has a convex appearance in distinction to the depressed appearance of *T. complicata*. Nevertheless there is considerable resemblance between the two forms.

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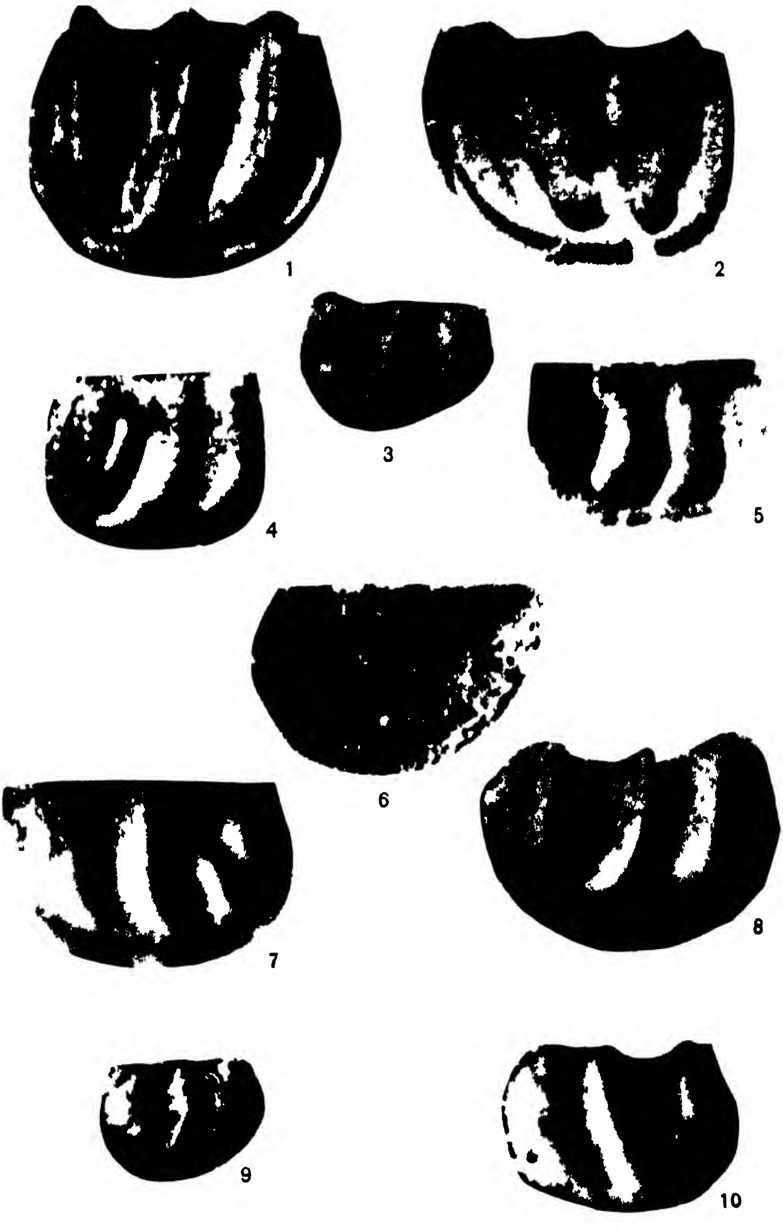


SOME ORDOVICIAN SPECIES OF *TETRADELLA*.

EXPLANATION OF PLATE

FIG. 1.—*Tetradella scripta* sp. nov. Right valve. Plasticene cast of holotype GSM. 74875A (× 15).
FIG. 2.—*Tetradella scripta* sp. nov. Right valve. Holotype. GSM. 74875A. External impression (× 15).
FIG. 3.—*Tetradella complicata* Right valve (Salter). Topotype. Llandeilo, Llan Mill, Narberth. GSM. 24527 (× 12). Internal mould.
FIG. 4.—*Tetradella bicuneiformis* sp. nov. Right valve. Plasticene cast of holotype external impression. GSM. 75421A (× 17).
FIG. 5.—*Tetradella salopiensis* sp. nov. Left valve. Holotype external impression. GSM. 75421C (× 17).
FIG. 6.—*Tetradella superciliata* (Reed) Left valve. External impression. Sedgwick Museum A 10983*a*, (× 17).
FIG. 7.—*Tetradella salopiensis* sp. nov. Left valve. Plasticene cast of holotype external impression. GSM. 75421C (× 20).
FIG. 8.—*Tetradella scripta* sp. nov. Left valve. Paratype GSM. 74875B. Internal mould (× 14).
FIG. 9.—*Tetradella salopiensis* sp. nov. Right valve. Holotype internal mould GSM. 75422C (× 10).
FIG. 10.—*Tetradella bicuneiformis* sp. nov. Left valve. Paratype internal mould GSM. 75422B (× 15).

A Method of making Thin Sections from Friable Materials and its use in the Examination of Shales from the Coal Measures

By J. W. Fowler and J. Shirley

(PLATES XI AND XII)

DURING the investigation of certain water-soluble and porous materials it was necessary to produce thin sections showing their structure and crystal composition. Using water as a lubricant during the thinning of the sections the specimens tended to break up and essential constituents were lost through solution, while paraffin had a marked solvent action on the canada balsam cement resulting in disintegration of the thin section and contamination by particles of carborundum.

Synthetic plastics are available in great variety and a search has been made for one as a possible substitute for canada balsam which, while unaffected by water or paraffin, would have the adhesive properties which make canada balsam so generally useful as a cement in microscopical work. Among the many which have been tried, one thermoplastic resin, Santolite, M.H.P., has been found to have the necessary properties. It is transparent and colourless, and has the additional advantage of stability on heating. It softens at 62° C. and has a refractive index of between 1·58 and 1·6. Santolite M.H.P. is a product of the Monsanto Chemicals, Ltd., to whom we are indebted for co-operation during the investigation.

This cement has made it possible to prepare from a wide variety of boiler deposits, thin sections which have proved of great value in work concerned with the mode of formation and possibilities of control of these deposits.[1]

The successful application of this thermoplastic in the original investigation led to attempts to use it for making thin sections from other substances which are found to be very difficult by the ordinary methods. For example, it has been possible to produce good sections of normal thickness for petrological investigation from friable rocks and dried muds and clays which readily disintegrate on wetting and by the usual methods give thin slices lacking many of the essential features necessary to a full study. The Santolite thermoplastic cement has been proved specially suitable in the preparation of thin sections from friable and very weathered shales of both marine and non-marine origin.

It is recognized that impregnation with thermosetting or air

[1] Bull. M.C/160, p. 31. Seven Papers on Boiler Availability. *Boiler Availability Committee.* London.

hardening resins can render friable materials amenable to thin-sectioning technique, but the use of these substances usually involves extra manipulation and sometimes additional apparatus. Moreover, the cemented blocks often present difficulties in making thin sections due to the widely differing hardness of the solidified resin and the material under examination.

As an example a method will be described of preparing a thin section from a weathered Coal Measure shale taken from the outcrop. The shale is first allowed to dry *slowly* in the laboratory, since any attempt to hasten drying will usually lead to further disintegration. A suitably sized piece is then placed in a shallow vessel (a tin lid will serve) containing molten Santolite and maintained, on a hot plate, at a temperature of about 100° C. until thoroughly impregnated. The time for this is generally not longer than two hours. The shale is then removed and allowed to cool. A flat surface is prepared by rubbing, without lubricant, on medium grained emery or carborundum paper supported on a piece of plate glass. If, after rubbing on emery paper, the surface is seen to be imperfectly impregnated, the specimen must be heated a second time in the molten Santolite. The surface then receives a final polish by rubbing on a piece of plate glass charged with very fine carborundum (No. 600) using paraffin as a lubricant. The smooth surface is wiped clean with a dry cloth, and the shale is then mounted on a glass slide with Santolite as a cement. It has been found convenient to rub a piece of Santolite on a hot slide until there is sufficient in the molten condition, on the surface of the glass. The prepared surface of the shale, slightly warmed, is firmly pressed on the cement and bubbles worked out. A useful method at this stage is to hold the specimen between the thumb and fingers of one hand and apply pressure to the surface of the slide with a suitably shaped piece of wood. By this means the dispersion of the bubbles from the cement can be observed. When the cement has cooled and set hard the shale is cut with a fine hacksaw to leave a thickness of about one-tenth of an inch. This is further reduced by rubbing on a sheet of medium grade emery paper on a glass plate by the same method as used during the preparation of the original face. Care is necessary at this stage to avoid scratching the slice or loosening the cement. The final thinning of the section is completed on a sheet of plate glass by rubbing with fine carborundum (No. 600) with paraffin as a lubricant. The final thickness of the section depends to some extent on the nature of the material but it has been found that the normal thickness is readily achieved and in the case of dense black shales thinning may be taken further. During this final stage it is convenient if the section can be wiped clean and frequently examined under a polarizing microscope to judge the thickness of the slice. (A cloth should be kept specially for

this purpose to avoid contamination by coarser carborundum or other gritty material.) The surface of the slice is then stroked with the palm of the hand to remove any textile fibres still adhering and is ready for the application of the protective cover slip. Since any attempt to apply heated balsam or to warm the finished slice would spoil the section, the cover slip is mounted with previously prepared balsam. The correct consistency is secured by warming a small wide-mouthed bottle of fresh canada balsam on a hot plate at about 100° C. until when cold the balsam is a stiff syrup. In mounting the cover slip, sufficient of the prepared balsam is smeared on the surface of the section and a cover slip of adequate size placed in position. On top of this is arranged a piece of glass cut from an old photographic plate, rather smaller than the cover slip. Pressure is gently applied to the plate by the use of a simple clamp and adjusted by inserting a small cork between the piece of glass and the screw head of the clamp. Surplus balsam is thus squeezed out and is removed by means of a heated knife blade. (An old razor of the "cut-throat" variety is very useful for this purpose.) The section is finally cleaned by placing for a few minutes in a shallow dish containing acetone or amyl acetate, wiping with a wad of cotton wool soaked in the solvent, followed by a thorough washing in soapy water and a last rinse under the tap.

In the case of soft porous materials such as dried muds or clays, an approximately flat surface is prepared on a piece of convenient size by cutting with a knife or hacksaw, and is further smoothed by rubbing on emery cloth. With materials of this type the impregnation is best secured by using a solution of Santolite in acetone or amyl acetate, sufficiently mobile to wet and penetrate the mass of the dried mud. The specimen is heated in the solution in a suitable container until the solvent is evaporated, and the temperature maintained for a short time at about 100° C. This operation is conveniently completed on a hot plate but care should be taken to avoid risk of fire. When thoroughly impregnated the block is removed, allowed to cool and treated in the same manner as in the preparation of a thin section from weathered shale.

A simple modification of the method has enabled thin sections to be made from chippings such as these recovered from borings drilled by chiselling or rotating cone bits. The chippings are first dried and then placed in a small tapered copper beaker containing a depth of about half an inch of molten carnauba wax. The chippings should be well covered with the wax and heating continued on a hot plate until the bubbling has ceased. The beaker is then cooled and when the wax has solidified the block containing the embedded chippings can be removed by inverting the beaker and tapping lightly. The block is sawn across, the surface so obtained flattened by rubbing

on a plate with fine carborundum (No. 600), using paraffin as a lubricant. Shale fragments are generally so shaped that they arrange themselves with the bedding more or less parallel to the bottom of the beaker, and if sections across the bedding are desired the block may be cut vertically. The block is mounted on a glass slide with Santolite M.H.P. as cement at as low a temperature as possible since the wax softens at about 20° C. above the melting point of Santolite. The block is then reduced to a thin slice by sawing off with a hacksaw and rubbing on coarse to medium emery cloth supported on a glass plate. It is finally reduced to normal thickness by rubbing on a glass plate with fine carborundum and paraffin as a lubricant. In the final stage of thinning care is necessary to prevent fouling of the plate by wax. This is best done by rubbing with very gentle pressure. If, during the mounting, the chips have been slightly disturbed it will not be possible to produce a transparency of uniform thickness and in this case the thicker parts may be reduced by rubbing with the finger covered by a small piece of cloth dipped in fine carborundum and paraffin. A useful piece of apparatus for viewing the thin section in the final stage and touching up with the finger is an inclined piece of ground plate glass, illuminated from below in the form of a simple photographer's retouching desk. The slice is then cleaned and the cover glass mounted with canada balsam as already described. Plate XII, figs. 3 and 4, illustrate thin sections prepared by this method from borehole chippings.

During the development of the methods described above many different specimens of shales, in all stages of preservation have been sliced, and the final stage of the thinning of the sections have been controlled by frequent examination under the petrological microscope. It has not been our intention to conduct a petrological research but as the result of this incidental study on a series of thin sections of unusual quality it has become apparent that significant differences are to be seen between shales of differing origins.

In the stratigraphical correlation of Carboniferous strata other than limestone, emphasis in modern work is often laid on the sequence of marine bands. In the Millstone Grit series these are recognized by the different species of goniatites occurring in them but in the Coal Measures the marine bands are characterized by *Lingula* sp. occurring alone or in company with goniatities, which are often badly preserved, and occasionally other marine organisms. A series of thin slices prepared by the methods described above from several marine bands of the Coal Measures and Millstone Grit has demonstrated that it is possible to recognize their marine character in thin section and suggest therefore, that chippings of shales from deep bores may be identified as marine or non-marine where the chance of finding macroscopic

fossils is very remote. The characters which make this possible are firstly palaeontological and secondly petrographical.

The most widely distributed and easily recognizable members of the marine microfauna in these bands are foraminifera. The mere recognition of foraminiferal remains is sufficient to define the enclosing rock as marine and this goes a long way towards correlation, where the successional ladder of marine bands is already as well known as it is in the Coal Measures. In a series of thin sections from several localities and horizons it is possible to illustrate the stages from complete preservation of the foraminiferal shell (Plate XI, fig. 4) to almost complete replacement by granular pyrites (Plate XI, fig. 3). At any stage the shell may be dissolved away, leaving only a vague spiral arrangement of the infilling to mark the former structure (Plate XI, fig. 1), or in extreme cases a shapeless mass of material of different colour and composition from the groundmass (Plate XII, fig. 1). In some cases the shells have been filled with Kaolin-like material of very fine grain. Often the shells are very badly preserved and in only one or two instances have we tentatively suggested a generic identification. In all of the marine bands there are small patches of Kaolin which may be the last representative of broken down skeletons of foraminifera. In the Two-Foot Marine Band these patches of Kaolin are frequent but recognizable foraminiferal remains are rare. In the more truly marine shales of the Mansfield Marine Band, the Clay Cross Marine Band, and those of the Millstone Grit, other organic remains of small size are found, such as very immature goniatites or gastropods, and numerous small rods often with pointed ends which may be sponge spicules. None of these bodies have been seen in shales with non-marine lamellibranchs, except possibly in the thin non-marine intercalates in the Clay Cross Marine Band.

Foraminifera have been reported from Coal Measure Marine Bands in the Warwickshire Coalfield (Stubblefield in Mitchell, 1942, p. 20 and 23), and have been recognized independently by Stubblefield in the Clay Cross and other marine bands in Nottinghamshire. In some of these cases the foraminifera were found as whole specimens in the friable weathered outer crust of ironstone nodules.

The dark shales with marine fossils are all of a similar appearance in thin slice under the microscope but it is difficult to suggest a constant, always recognizable difference from similar shales with non-marine lamellibranchs. In those we have examined, the marine shales consist of a groundmass of indeterminate fine-grained muddy material, with much carbonaceous debris in which quartz grains about ·025 to ·05 mm. diameter are scattered. The quartz grains appear as points of light under crossed nicols. In the non-marine carbonaceous shales there is a similar groundmass but the quartz grains are less numerous and

FIG. 1

FIG. 2

FIG. 3

FIG. 4

THIN SECTIONS OF CARBONIFEROUS SHALES.

FIG. 1

FIG. 2

FIG. 3

FIG. 4

THIN SECTIONS OF CARBONIFEROUS SHALES.

much more scattered. A further feature of the non-marine shales is the presence of microspores. These are rare or much less numerous in the marine shales, at least so far as we have had opportunity of examining them. The differences in appearance under the microscope between marine and non-marine shales which have been outlined above are subtle and difficult to describe. Nevertheless we are satisfied that with good quality thin sections which are possible by the method described above, significant differences are to be observed. Our preliminary study gives hope that with growing experience marine shales may be distinguished on petrological as well as paleontological grounds.

This paper is published by permission of the Director of Fuel Research and the Director of the Geological Survey and Museum, of the Department of Scientific and Industrial Research. The illustrations are Crown Copyright, and are published by permission of the Controller, H.M. Stationery Office. We also thank our colleagues for suggestions and friendly criticism during the progress of the work.

REFERENCE

MITCHELL, G. H., 1942. Geology of the Warwickshire Coalfield, with Animal Palaeontology, by C. J. Stubblefield, and Plant Palaeontology by R. Crookall. *Geological Survey, Great Britain*, Wartime Pamphlet No. 25.

EXPLANATION OF PLATES

PLATE XI

FIG. 1.—Section parallel to bedding. Shales with *Lingula* sp. Borehole at Darlton, near E. Markham, Nottinghamshire, at 2,861 ft. below surface. The foraminiferal shells are partly replaced by granular pyrites and Kaolin. × 66.

FIG. 2.—Section parallel to bedding. Shales with *Gastrioceras cancellatum*. Borehole at Senior's Brewery, Shepley, Yorkshire, 803 ft. below surface. The helical spiral is probably a minute gastropod and other shells are immature goniatites. × 66.

FIG. 3.—Section parallel to bedding. Clay Cross Marine Band. Bore hole at Ollerton Colliery, 329 ft. below the Top Hard Coal. The foraminiferal shell is filled with pyrites. × 66.

FIG. 4.—Section parallel to bedding. Weathered shales with *Gastrioceras crencellatum*, Millstone Grit. Fulwood Mills, Sheffield. *Hemidiscus* sp. with chitinous shell and filled with Kaolin. × 66.

PLATE XII

FIG. 1.—Section parallel to bedding. Two Foot Marine Band, Monckton Colliery, Yorkshire. An irregular patch of Kaolin. × 66.

FIG. 2.—Section of " cank " (Mudstone cemented with Siderite). Mansfield Marine Band, Stairfoot Brick Works, near Barnsley, Yorkshire. An immature goniatite shell. × 66.

FIG. 3.—Section of borehole chippings embedded in carnauba wax. " Sinks " from 1 ft. 6 in. coal at 2,691 ft. Gringley oil bore, near Gainsborough. × 1¾.

FIG. 4.—Portion of Fig. 3 enlarged to show shale fragment with foraminiferal shell. × 66.

A Seismic Investigation of the History of the River Rheidol in Cardiganshire

By H. P. Coster and J. A. F. Gerrard

(Department of Geodesy and Geophysics, Cambridge)

Introduction

In its upper reaches the River Rheidol flows south, parallel to the coast of Cardiganshire, and about ten miles inland. At Devil's Bridge it turns sharply to the west (Text-fig. 1) and enters the sea at Aberystwyth. Due to rejuvenation the river has, in its southward course, incised the floor of its old mature valley the form of which is still clearly visible, and which continues to the south beyond Devil's Bridge to Pontrhyd-y-groes and Tregaron. This part of the valley now contains only small streams.

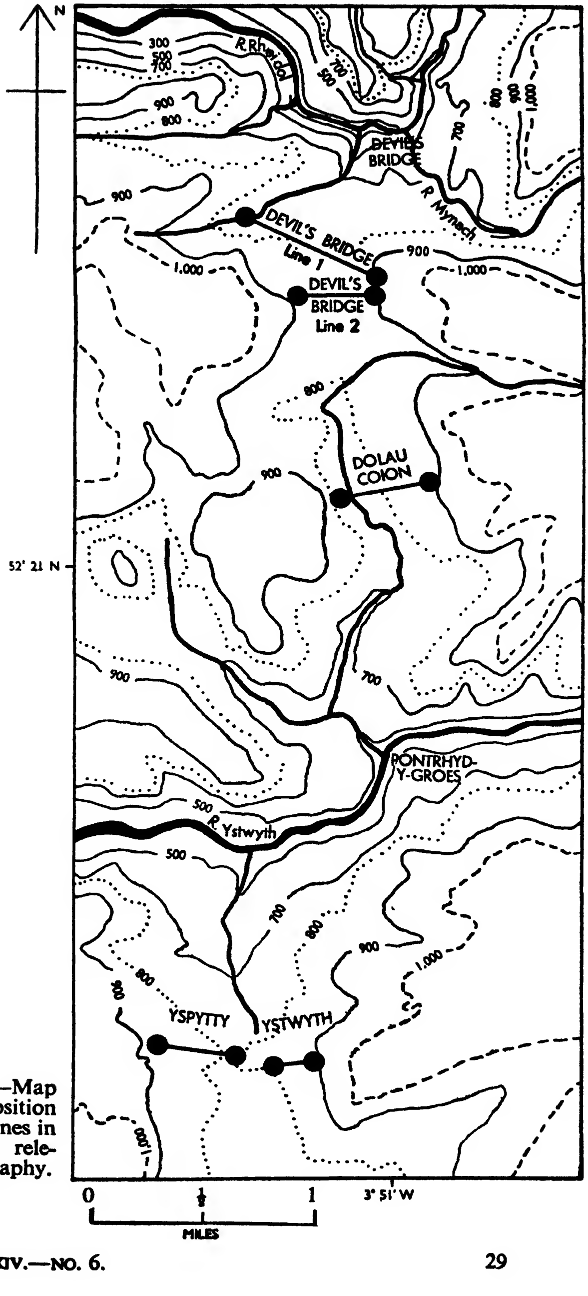
Jones and Pugh (1935) have discussed the history of this river system in detail. They attribute rejuvenation and the sharp westerly turn to be the result of capture by a westerly flowing stream eroding back its head to the east. A similar capture has occurred three miles to the south, near Pontrhyd-y-groes, leaving the section of the old valley between there and Devil's Bridge at a much higher level than the floor of either of the east–west valleys.

About three miles north of Devil's Bridge the river appears to be an incised meander, but Jones and Pugh point out that this is not true. The river previously followed a more direct course to the east of its present bed, but was deflected by ice pressing down into the valley from the east, and forced to flow along the western extremity of the ice. The older valley is drift-filled and can be seen where it intersects the present channel. These observations show that the rejuvenation of the river and the capture which went with it must have been well advanced by the Pleistocene. After the ice had retreated the mature valley was left covered with a layer of drift.

The object of the work described in this paper was to apply the seismic method to the determination of the thickness of overburden in the valley in order to compare the results with the longitudinal section of the bedrock floor of the valley system given by Jones and Pugh.

Technique

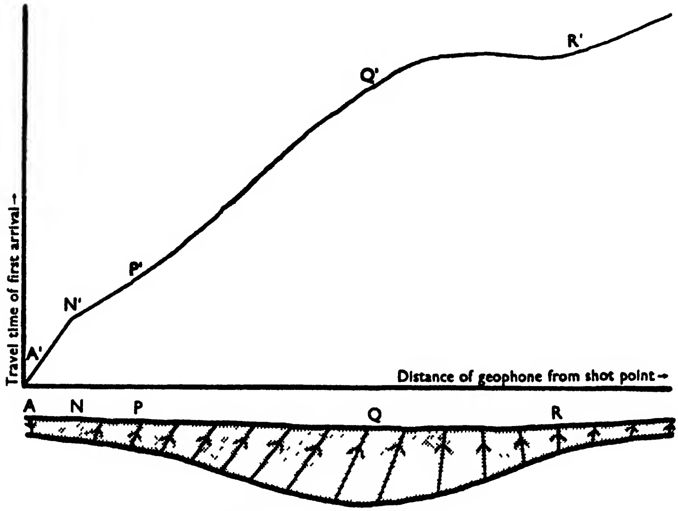
There is little literature on the determination of the cross section of steep-sided channels filled with unconsolidated material. In this section a description is given of the methods employed in the present series of experiments.



TEXT-FIG. 1.—Map showing position of seismic lines in relation to relevant topography.

The geophones were spread in a line across the valley so that they were very near the bedrock outcropping at either end. A small charge was exploded from the bottom of a hole bored at one end of the line, and a graph of the time of the first arrival at each geophone was plotted against the distance of that geophone from the shot point.

Suppose Text-fig. 2 represents a section of the valley, with its associated time-distance graph, the shot being at A. The slope of the graph A' N' corresponds to the velocity in the overlying sediments. Further over the channel, at P. Q, and R, the refracted wave



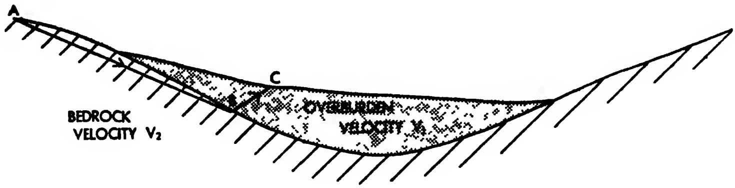
TEXT-FIG. 2.—Diagram showing a section of bedrock-overburden interface and associated time-distance graph. The refracted rays through the overburden are indicated.

is the first to arrive, and the apparent velocity measured along the surface will depend on the velocities in the bedrock and overburden, and on the slope of their interface. Between P and Q the interface dips so that the velocity measured will be smaller than the bedrock velocity, and between Q and R the velocity will be greater than that in the bedrock. If this interface is sufficiently steep the measured velocity may be infinite or negative, the wave arriving at a geophone at the same time as, or before, that at the adjacent geophone nearer the shot.

To calculate the shape of the interface from the time-distance graph it is necessary to know three quantities, the velocity of sound through the overburden, the true velocity through the bedrock, and the thickness of overburden beneath the shot point. The last of these may easily be found if the interface beneath the shot point is plane. In this case

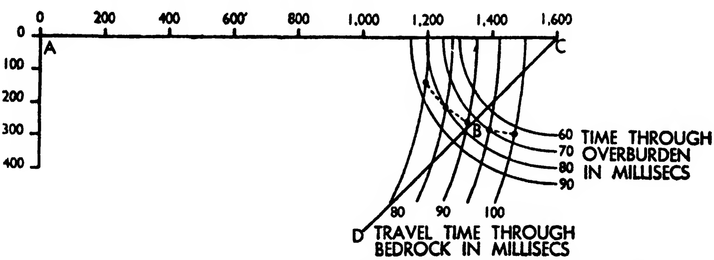
N' will be the intersection of two straight lines, and the depth can be determined using the standard formula. The true velocity in the bedrock was found by shooting a line in both directions on part of the ground known to overlie a plane interface. The velocity can be found from the slope of the time-distance graphs for the two shots.

As a simple example consider a valley with rock outcropping on



TEXT-FIG. 3.—Diagram showing ray path from shot point A to geophone C, the refraction taking place at the point B on the bedrock-overburden interface.

both sides (Text-fig. 3). A wave is propogated from the shot at A and received by a geophone at C after a time t. Let B be the point on the interface where refraction takes place. Then $t = AB/V_2 + BC/V_1$ where V_1 is the velocity of sound through the overburden, and V_2 the velocity through the bedrock. This is an expression for the locus of the point of refraction B for a given time of arrival, but only one point on this line can lie on the interface. This may be



TEXT-FIG. 4.—Diagram showing construction for finding point of refraction on interface.

found as it is known that the refracted ray meets the surface at an angle θ where $\cos \theta = V_1/V_0$, V_0 is the apparent velocity along the surface, and is the reciprocal of the tangent to the time-distance graph at the point corresponding to the geophone at C. A graphical method is the simplest way of finding B.

A section of the surface of the ground is drawn (Text-fig. 4), the position of shot point A, and geophone C being indicated. First the ray DC arriving at the geophone is plotted, the angle it makes with

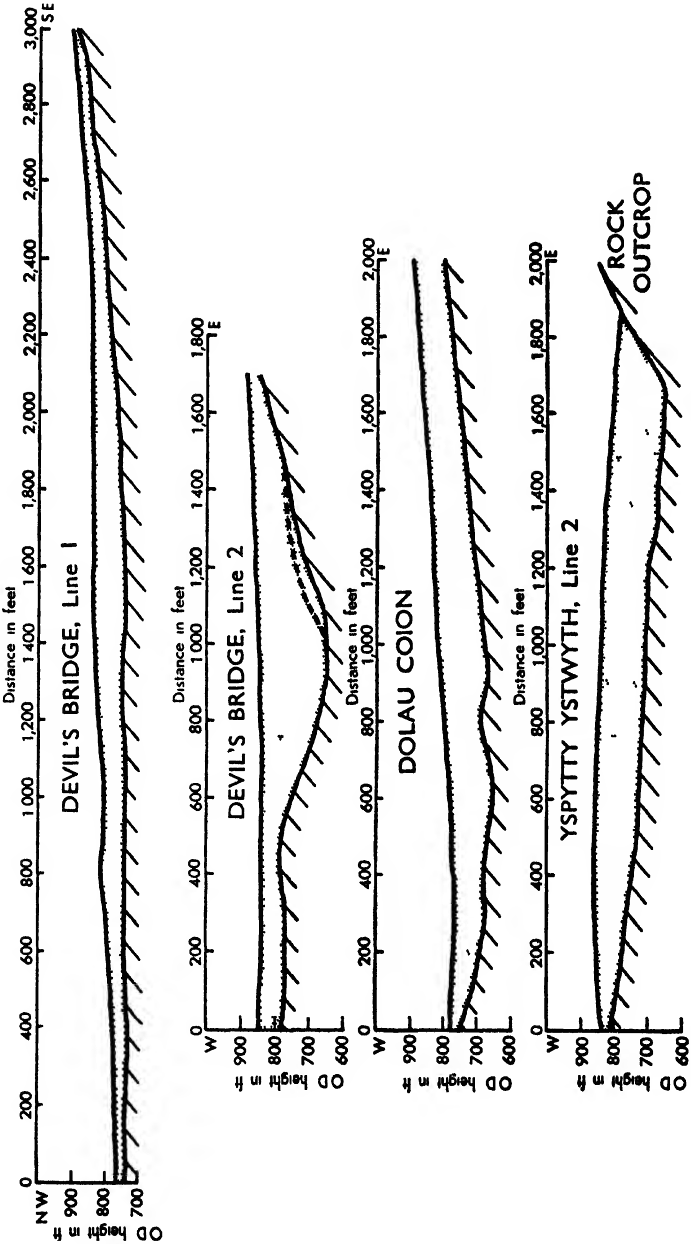
the surface being θ. Arcs are described about A with radii representing the distances travelled in the bedrock for time intervals of 5 milliseconds. Taking C as origin, another set of arcs is drawn corresponding to distances travelled in the overburden for time intervals of 10 milliseconds. Thus in the example shown in the diagram the separation of shot point and geophone is 1,400 feet, the total travel time measured on the recording apparatus is ·165 seconds, and the apparent velocity at C is 7,100 ft./sec. The velocity of sound through the bedrock is 15,000 ft./sec. and through the overburden 5,500 ft./sec. This makes $\theta = \cos^{-1} 5{,}500/7{,}100 = 39°$. Arcs are described about A at 5 millisecond intervals and about C with an interval of 10 milliseconds. The intersection of the 95 millisecond arc through the bedrock with the 70 millisecond arc through the overburden satisfies the travel time requirement. This is true also of the 85 and 80 millisecond arcs, and these together with interpolated values constitute the dotted line which is the locus of points satisfying the travel time. The intersection of the dotted line with DC gives the point on the interface, B, where refraction takes place. If the slope of the time-distance graph is changing rapidly the measurement of the apparent velocity at the geophone may be in error. This gives rise to an error in θ, but the resulting error in the location of the true interface is likely to be small, as this interface and the locus of points of equal time of arrival have a common tangent at the point of refraction. This is true because the point of refraction on the interface satisfies the principle of minimum travel time.

The main error remaining in the determination of the thickness of drift is due to an incomplete knowledge of the true velocities of sound through the bedrock and overburden. In the present work the standard error in both these quantities is about 500 ft./sec. which gives rise to a standard error of approximately $\pm$ 10 per cent of the calculated depth of the valley.

Description of Experiments

Measurements were made at five sites placed at intervals down the valley. Two were just south of Devil's Bridge, one was at Dolau Coion, one mile to the south, and two at Yspytty Ystwyth, two and a half miles further south. The locations are shown in Text-fig. 1.

The Dolau Coion section will be discussed first. Three lines were shot, one from the western side of the valley, the geophones being spread 2,000 feet to the east, one from the eastern extremity of the previous line with the geophones spread 1,000 feet to the west, and one from the centre of the first line, the geophones lying 1,000 feet to the east. The last two shots yielded time-distance graphs not significantly deviating from straight lines, so that the interface between



TEXT-FIG. 5.—Sections found beneath the seismic lines at intervals down the valley system.

them may be assumed to be plane. These two shots allowed the true bedrock velocity to be determined ; it was found to be 15,000 ft./sec., a value adopted in all further computations as it was confirmed at other sites. The velocity in the overlying drift was found to be 5,500 ft./sec. Using these data the Dolau Coion section shown in Text-fig. 5 was computed. The depth of the bedrock computed from the 2,000 feet shot agreed to within 7 feet of the values obtained from the two shorter shots. The maximum depth to bedrock was 125 feet $\pm$ 13 feet. The $\pm$ 13 feet represents the approximate standard error of the depth determination.

Devil's Bridge, Line 1, was shot from the eastern side of the valley, the geophones being spread to a rock outcrop to the west of the centre of the valley. The line was extended from the outcrop to the western side of the valley, but here the bedrock was found to be close to the surface, its maximum depth being about 40 feet. The longer line yielded the section shown in Text-fig. 5. The maximum thickness of glacial drift, 100 $\pm$ 11 feet, is to be found at a distance of 1,400–1,500 feet from the shot point.

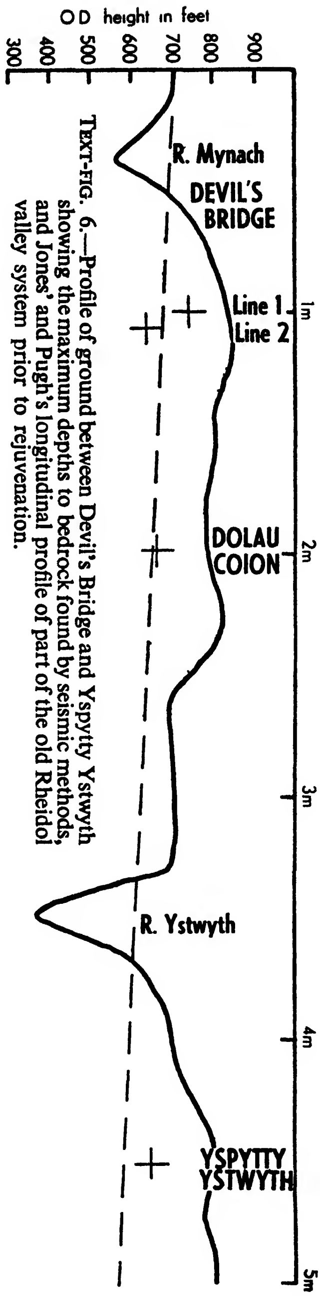
Devil's Bridge, Line 2, was located 700 feet south of Line 1. Two shots were fired, one from the eastern side of the valley, the geophones being spread nearly to the rock outcrop on the far side, a distance of 1,700 feet. The second shot point was situated in the centre of the valley 1,100 feet to the west of the first shot. The interface was calculated independently from both shots. The computed sections were in good agreement near the ends of the shorter line, but there was a discrepancy for the geophones lying 500 to 800 feet from the western shot, the depths calculated from this shot being up to 40 feet smaller than those calculated from the eastern shot. This discrepancy may be due to the fact that the ray paths from the two shot points took completely different paths through the bedrock, which could happen if the floor had considerable relief. If there was a step running across the valley almost parallel to the seismic line, the first arrivals to the geophones between the shot points may have travelled from one shot along the floor of the valley, whereas from the other shot the quickest path may have been along the side of the step. The arrival times for the geophones at the end of the line should, of course, agree. The line shot from the east is shown as a solid line in Text-fig. 5, and that shot from the west is shown as a dotted line. Both lines yielded the same maximum depth of 190 $\pm$ 20 feet due to the fact that the deepest part is near the western shot point.

The section at Yspytty Ystwyth was located so that the seismic line could be split up into two parts, a large outcrop of bedrock in the middle of the valley permitting a separate line to be shot from either side. Line 1, shot on the eastern side, showed that nowhere does

there exist more than 35 feet of drift. Line 2, to the west of the outcrop, was shot from both ends, there being an overlap of 700 feet in the spread of the geophones. The coincidence of the computed interface acted as a check on the accuracy of the method. The computed interface for the western section is shown in Text-fig. 5. The greatest thickness of drift is 160 ± 16 feet found 250 feet from the rock outcrop in the centre of the valley. The slope of the bedrock here is over 30°, very steep if it comprises the side of a mature river valley.

CONCLUSIONS

Text-fig. 5 shows the cross sections of the valley found at the four sites, and it is seen that all, with the possible exception of that at Yspytty Ystwyth, have the form of a mature river valley. Examination of the mature valley above Devil's Bridge indicates that if the old river continued directly to the south it should have a gradient of about 20 ft./mile. Text-fig. 6 shows a longitudinal profile of the valley, with a dotted line inserted showing the old floor of the Rheidol valley according to Jones and Pugh. The maximum depths to bedrock found at the seismic stations are marked +. It is seen that these points do not lie on the graded line as would be expected if the rock floor were part of a mature valley. Devil's Bridge, Line 1, and Line 2 at Yspytty Ystwyth give bedrock well above the level indicated by Jones and Pugh. The depths at Devil's Bridge, Line 2, and Dolau Coion are very near the graded line. All the seismic evidence supports



TEXT-FIG. 6.—Profile of ground between Devil's Bridge and Yspytty Ystwyth showing the maximum depths to bedrock found by seismic methods, and Jones' and Pugh's longitudinal profile of part of the old Rheidol valley system prior to rejuvenation.

the view that there is a step in the valley between Devil's Bridge, Lines 1 and 2, and that the floor of the old valley must have been at least as high as the bedrock at Devil's Bridge, Line 1, and Yspytty Ystwyth. This shows that erosion has taken place since the valley was abandoned by the river. The form of the step at the constriction near Devil's Bridge, Line 2, brings to mind the steps at constrictions in valleys abandoned by glaciers.

The seismic results yield no definite evidence on the order in which the two captures of the valley took place. A gradient of about 20 ft./mile can be drawn through the deepest points of the sections at Devil's Bridge, Line 1, and Yspytty Ystwyth, and this implies that the capture at Devil's Bridge took place first, otherwise the gradient would have been much smaller. If, however, subsequent erosion has taken place, this is by no means definite.

REFERENCE

JONES, O. T., and PUGH, W. J., 1935. The Geology of the Districts around Machynlleth and Aberystwyth. *Proc. Geol. Assoc.*, xlvi, 247.

REVIEWS

GEOLOGICAL STRUCTURES AND MAPS. A Practical Course in the Interpretation of Geological Maps for Civil and Mining Engineers. By A. ROBERTS, pp. vii + 66, with 30 figures and 39 map exercises. Pitman, 1947. Price 12*s*. 6*d*.

The solution of geological map problems is one of the most generally useful applications of geological science and yet there are few books which can be recommended to the student which do not insult his intelligence or fail to arouse any interest. Geologists as well as engineers will be indebted to Mr. Roberts for this book, which goes some way towards meeting the need.

The didactic aspect is brief, elementary, and broken into short chapters with headings and illustrations so that he who does not read may see what he is missing. This is followed by a series of exercises in thirty-nine steps, covering most simple aspects of " problem maps ". These maps are a useful addition to our teaching resources and should present a challenge to the student. The " cut and dried " treatment is an advantage but it is linked with a somewhat naïve dogmatism remote from geological experience.

To many mapping problems there are countless solutions and it is a matter for geological and mathematical judgment to select the nicest. The helpful phrase " assuming constant dip and thickness " is too often left to the imagination. Constructed maps bear little relation to reality and are none the less useful for that ; but there are unwritten codes demanding internal tidiness and the reviewer has been distracted by apparent neglect of this in some maps ; for example, in Map 25 the topographical contours appear to pass below sea level without a coastline ; in Map 30 outcrop Y appears misplaced ; drawing sections to natural scale is rightly recommended but the early maps illustrating this have unusually high relief, while in Map 32 vertical exaggeration would enable more accurate measurement ; in Map 37 too little is given to delineate the base of the Grit and too much if this is not expected.

We hope an effort will be made to improve the details and increase the scope in the next edition, but in the meantime the reviewer would recommend his own students, at least, to buy the book and use it.

W. B. H.

AN INTRODUCTION TO PALAEONTOLOGY. By A. MORLEY DAVIES. 2nd edition, pp. xi + 372, with 118 figs. Thos. Murby and Co., London, 1947. Price 18*s*.

There are three well-known British textbooks of Palaeontology : Mr. H. Woods's *Palaeontology*, which has just gone out of print again

(in the eighth edition), but is said to be reprinting; *Outlines of Palaeontology*, by Professor H. H. Swinnerton, of which the third edition is reviewed on p. 372; and this, by Dr. A. Morley Davies, to the long-awaited second edition of which we extend a warm welcome. Each is decidedly individual in treatment; and the emphasis might it is hoped without injustice, be concisely defined as morphological, evolutionary, and systematic respectively. The student who has access to all three is indeed fortunate.

Apart from a greater emphasis on systematics and classification, Dr. Davies's book retains in its second edition the two very distinctive features that characterized the original. The first of these is the unorthodox arrangement of the phyla, beginning with the brachiopods, passing to the mollusca, arthropods, vertebrates, graptolites, coelenterates, and ending with the sponges and foraminifera. It may be, as claimed in the Preface, that this order "avoids the difficulties associated with the more usual methods of beginning either with the simplest or the most advanced organisms", but any such advantage must be weighed against the sacrifice of that view of increasing complexity which can be built up by following the animal kingdom steadily through from forams to vertebrates.

The second distinctive feature, the method of introducing each phylum with the "detailed description of selected fossil species", is an interesting adaptation of the method familiar in zoological practice of illustrating a phylum by means of a "type". Carefully followed by teacher and student, it should give real familiarity with a very restricted range of fossils, in place of (at worst) the vaguer conception of the bristling features of that hypothetical "typical trilobite" (or whatever it may be), to which we are often so liable to revert. But if we are to make clear the significance of fossil remains as once-living animals we must sooner or later (even in Dr. Davies's method) refer for interpretation to some living representative; and those who follow the orthodox method usually adopt at the outset some living form as illustration. In the reviewer's experience, the most difficult groups to introduce are the extinct groups whose morphology is accordingly to a greater or lesser extent difficult to interpret.

In any event, the palaeontology student even in his most elementary stage cannot, like the zoologist, rest content with a type or even half a dozen types for each phylum; for the stratigraphical uses of palaeontology demand the ability to recognize quite a large number of genera (and/or species) from even imperfectly preserved material. With the orderly arrangement and classification of these, Dr. Davies's book certainly comes into its own, for the student not unnaturally wants a system even while deploring its terminology. And Dr. Davies's book will give him familiarity not only with the main subdivisions

but (if he uses his wits) with the principles of classification in each phylum.

The second edition has been apparently slightly extended and contains a number of new figures, though it is compressed into rather fewer pages. It retains that extremely useful chapter on the Rules of Nomenclature—the only elementary exposition known to the reviewer of the seemingly wilful vagaries of the systematist. There is also a short chapter on fossil plants and on the collection and preservation of fossils, and an appendix on stratigraphical palaeontology.

To say that every specialist may perhaps find a small amount to disagree with in his own section is in no way to detract from the merits of an excellent elementary textbook.

O. M. B. B.

A HANDBOOK OF ROCKS. By J. F. KEMP, 6th edition, revised and edited by F. F. GROUT. pp. viii + 300, with 96 figs. New York: D. Van Nostrand Company, Inc. Reprinted 1946 (Macmillan and Co., London). Price 20*s*.

This well-known handbook by the late Professor J. F. Kemp has now been thoroughly revised and brought up to date by Professor F. F. Grout, of the University of Minnesota. Unlike most textbooks on the subject, Kemp's *Handbook* is intended primarily for the study of rocks without the use of the polarizing microscope, and it thus forms a valuable companion volume to those others.

PETROGRAPHIC MICRO-TECHNIQUE. By A. V. WEATHERHEAD, with an introduction by A. K. WELLS, pp. x + 102, with 94 figs. London: Arthur Barron, Ltd., 1947. Price 12*s*. 6*d*.

The first portion of this book gives a detailed and well illustrated account of methods of preparing thin sections of rocks and minerals, together with improved methods of grinding and mounting, developed by the author. It includes a chapter on special methods, such as serial section cutting, impregnation, and embedding, and obtaining cellulose films of fossil plants, clays, etc. A short chapter on heavy residue mounts follows, while the final chapter is devoted to the photomicrography of rock sections.

This book should prove useful to all those who have to do with petrographic micro-techniques. A few errors of statement on polarized light in the Introduction ought to be corrected in a second edition.

S. R. N.

OUTLINES OF PALAEONTOLOGY. By H. H. SWINNERTON. 3rd edition, xii + 393 pp. Edward Arnold and Co. Price 30*s*.

This new edition of Professor Swinnerton's thoughtful and stimulating work will be much appreciated by geology students already familiar both with fossils and the factual information culled from other text-books of palaeontology, and, moreover, zoölogy students also should find this book helpful.

As in former editions, the book is entirely palaeozoological, covering the various invertebrate groups commonly found as fossils, and over one-third of the volume is still devoted to vertebrates. Particular attention and diagrammatic illustration is given to structural features, to their growth and application, and to more theoretical studies of variation and evolutionary trends. In this edition one of the more progressive aspects is the acceptance of proterogenesis as an evolutionary process. This is defined as a condition characterizing the final members of a series which was first manifested in the youth of the early members ; the author might perhaps have mentioned as well in this connection, arrested development or paedogenesis.

New data and illustrations have been introduced into various parts of the book ; and one notices that the vertebrate affinities of graptolites are treated with reserve, but that the Australian Middle Cambrian supposed early Echinoderma are accepted without question. In the preface it is stated that the most extensive revision has been effected in the sections dealing with Protozoa, Cephalopoda, Trilobita, and Fishes. The limits of space and the reviewer's competence do not permit adequate evaluation of these revisions except perhaps in one section, that of the trilobites ; this, despite possible criticism of some of its details of fact, illustration, and theory, remains one of the most valuable parts of the book. The introduction of new matter, however, has not invariably been fully co-ordinated with the remaining text. For example, the new time-range table indicates the presence of twelve trilobite families in the Devonian Period, whereas on the preceding page (p. 240) it is stated that only " about five families " are present. Such a fault may serve a useful purpose if it tempts the student to check facts and thus gain a critical approach to this and other text-books. Available evidence suggests that there are eleven Devonian trilobite families ; that in the table the Encrinuridae and Cyclopygidae have been recorded erroneously from that period ; and that the name Otarionidae (formerly Cyphaspidae) has been omitted. Unfortunately a recent announcement to the Geological Society of a probable Mesozoic age of various foraminifera, previously considered to be of Cambrian age, came too late to be incorporated into the foraminiferal revision. The only phylogenetic tree diagrammatized for a major

group in the first edition is now omitted. Such " trees " are sought after by many students, but with increasing knowledge these are frequently found to have been built on shifting sands, and presumably the ammonite " tree " of the first edition has proved no exception. The suggestion is offered that in a future edition an indication of the size of the fossils illustrated would be helpful to a beginner.

The publishers are able to market the book at the same price as the first edition by reducing its thickness and weight to one half, though the original number of pages and text-figures remains unchanged. The result is certainly a very handy volume.

C. J. S.

MOTHER EARTH. By T. A. RYDER. pp. 184 with 25 text-figures. Hutchinson's Scientific and Technical publications, 1947. Price 15*s*.

Mr. Ryder approaches his task with a light heart. His task is to give the general reader an account of the physical facts and theories of the Earth with its hydrosphere, atmosphere, solar system, and universe. His approach is conditioned by experience in adult education, and he has succeeded in producing a readable account.

Each topic is expounded in a brief, attractive way, and the supporting facts, especially numerical, are well chosen to stimulate the mind. The very forwardness and confidence of style will serve to put most readers on their guard. While boasting that the book contains the latest theories, the author has not always checked his assertions or qualified his generalizations. One gains the impression that he has had in mind the interest of his audience before the truth of his statements. Taken in the right spirit this may not be altogether bad, since science is but a useful fiction relative to some purpose. The " mother " metaphor is pursued a little relentlessly through the chapter headings, which may repel more readers than it attracts, but the sales and not the reviewer will show this, and it is his hope that the number and enjoyment of amateur geologists may be increased through this book.

W. B. H.

CORRESPONDENCE

GRAVITY STRATIFICATION IN THE CUILLIN GABBRO OF SKYE

SIR,—Rhythmic banding showing gravity stratification is well known from various overseas examples of basic plutonic rocks, but so far as we are aware it has only been recorded in Britain from the Belhelvie Gabbroic complex (Stewart, *Quart. Journ. Geol. Soc.*, cii 1947, 465–498). It is perhaps of interest, therefore, to record that gravity stratification is well developed in the Cuillin Gabbro in the area about Druim Hain (Druim an Eidhne). In this area, which Harker postulated as the centre of the original gabbro complex, some of the bands in the gabbro show a marked concentration of iron ore and ferromagnesian minerals at and near the base, while upwards, in the distance of a foot or so, there is a gradual passage into a leucocratic rock made up largely of felspar. Only certain bands show gravity stratification at all clearly; in other cases a fairly uniform band of one composition gives place abruptly to a band of another composition. The dip of the gravity stratified banding varies and is often high.

Geikie and Teall in their paper " On the Banded Structure of some Tertiary Gabbros in the Isle of Skye " (*Quart. Journ. Geol. Soc.*, l, 1894, 645–659), described the banding but did not describe the peculiarity now called gravity stratification; nor did Harker in the memoir on the Tertiary Igneous Rocks of Skye. Subsequent to our first noticing the gravity stratification during recent field work, Geikie's paper, " On the Basic and Acid Rocks of the Inner Hebrides " (*Quart. Journ. Geol. Soc.*, l, 1894, 212–229) was consulted. In this, an example of banding on Druim Hain showing fine gravity stratification, is figured (*op. cit.*, plate 13), but again there is no comment on the feature. Since gravity stratification only occurs occasionally among the other types of banding these early observers, if they noticed it, may have considered it a freak structure of little signficance, whereas recent work suggests that gravity stratification is a clue to the mechanism of solidification of those intrusions showing it.

F. H. STEWART.
L R. WAGER.

4th September, 1947.

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